(2)

US Army Corps of Engineers
Construction Engineering Research Laboratory

DTIC FILE COPY

USA-CERL TECHNICAL REPORT P-89/01
OCTOBER 1988

AD-A201 049

Facility Cost Simulation Models: A Basis for Replacement Policy

by
Kyu-Seung Whang
Alan Moore
Gonzalo Perez

Real property management is related to the serviceability or durability of building components and materials that are affected by numerous external and internal factors. Despite the complexity of this problem, the U.S. Army, as one of the few organizations worldwide owning a large building inventory, must constantly make decisions for improving managerial efficiency of facilities. Knowledge about the serviceability and durability of buildings is the key to informed decisions.

Simulation models were developed to (1) estimate maintenance and repair (M&R) cost by a facility's age, (2) evaluate replacement strategies, and (3) predict future cost requirements of facilities. The models consider a facility as a set of replaceable and nonreplaceable components.

The family housing facility category was chosen for model experimentation. Sixty percent of relative repair cost was shown to be a long-run optimal value as a facility replacement criterion. Continuous cost increases were predicted for replacement and M&R until the year 2010. After a temporary decline, facility cost was projected to peak around the year 2050 due to the continuous increase of replacement cost. M&R costs should stay relatively stable at a 2 percent level of the replacement value for the coming 100 years as shown by adopting the 60 percent relative repair cost sum criterion.

The three cost simulation models show a high potential for estimating operational and M&R costs for family housing. To assess the models' applicability to other Army facilities, similar investigations need to be conducted using, for example, barracks, administrative buildings, and training facilities.

Approved for public release; distribution is unlimited.

Carl O. Magnell

Carl O. Magnell, PE
Colonel, Corps of Engineers
Commander and Director

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No 0704 0188 Exp Date Jun 30 1986

1a REPORT SECURITY CLASSIFICATION Unclassified	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY 2b DECLASSIFICATION / DOWNGRADING SCHEDULE	3 DISTRIBUTION / AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
4 PERFORMING ORGANIZATION REPORT NUMBER(S) USA-CERL TR P-89/01	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION U.S. Army Construction Engr Research Laboratory 6b OFFICE SYMBOL (If applicable) CECER-FS	7a NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 4005 Champaign, IL 61820-1305	7b ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING / SPONSORING ORGANIZATION OCE 8b OFFICE SYMBOL (If applicable) DAEN-ZCI-F	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER OMA
8c. ADDRESS (City, State, and ZIP Code) Washington, DC 20310-2600	10 SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. / PROJECT NO / TASK NO / WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)
Facility Cost Simulation Models: A Basis for Replacement Policy (U)

12 PERSONAL AUTHOR(S)
Whang, Kyu-Seung; Moore, Alan; Perez, Gonzalo

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
final	FROM ______ TO ______	1988, October	100

16 SUPPLEMENTARY NOTATION
Copies are available from National Technical Information Service
Springfield, VA 22161

17 COSATI CODES

FIELD	GROUP	SUB-GROUP
13	13	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
simulation, buildings, facilities, maintenance, replacement, service life.

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

Real property management is related to the serviceability or durability of building components and materials that are affected by numerous external and internal factors. Despite the complexity of this problem, the U.S. Army, as one of the few organizations worldwide owning a large building inventory, must constantly make decisions for improving managerial efficiency of facilities. Knowledge about the serviceability and durability of buildings is the key to informed decisions.

Simulation models were developed to (1) estimate maintenance and repair (M&R) cost by a facility's age, (2) evaluate replacement strategies, and (3) predict future cost requirements of facilities. The models consider a facility as a set of replaceable and nonreplaceable components.

(Continued)

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS	21 ABSTRACT SECURITY CLASSIFICATION Unclassified
22a NAME OF RESPONSIBLE INDIVIDUAL Dana Finney	22b TELEPHONE (Include Area Code) (217) 352-6511, ext. 389 22c OFFICE SYMBOL CECER-IMT

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

Block 19. (Continued)

The family housing facility category was chosen for model experimentation. Sixty percent of relative repair cost was shown to be a long-run optimal value as a facility replacement criterion. Continuous cost increases were predicted for replacement and M&R until the year 2010. After a temporary decline, facility cost was projected to peak around the year 2050 due to the continuous increase of replacement cost. M&R costs should stay relatively stable at a 2 percent level of the replacement value for the coming 100 years as shown by adopting the 60 percent relative repair cost sum criterion.

The three cost simulation models show a high potential for estimating operational and M&R costs for family housing. To assess the models' applicability to other Army facilities, similar investigations need to be conducted using, for example, barracks, administrative buildings, and training facilities.

FOREWORD

This work was performed for the Office of the Chief of Engineers under Operations and Maintenance, Army (OMA). The OCE Technical Monitor was Janet Randle, DAEN-ZCI-F.

The work was conducted by the Facility Systems Division (FS) of the U.S. Army Construction Engineering Research Laboratory (USA-CERL). Dr. Whang is a Professor at the College of Business Administration, Korea University, and was a visiting scholar at the University of Illinois, Urbana-Champaign. Dr. M. J. O'Connor is Chief, USA-CERL-FS. The technical editor was Dana Finney, USA-CERL Information Management Office.

COL Carl O. Magnell is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

TABLES

FIGURES

FIGURES (Cont'd)

FACILITY COST SIMULATION MODELS: A BASIS FOR REPLACEMENT POLICY

1 INTRODUCTION

Background

The U.S. Army owns one of the largest building inventories worldwide. In efforts to manage this huge inventory effectively, the Army has focused on improving managerial efficiency and the decision-making process with respect to real property--particularly in determining maintenance and repair (M&R) and replacement requirements. Efficient management of real property is related to the serviceability or durability of building components and materials. The performance of building materials and components is affected by various degradation factors as shown in Table 1.

Due to the variety of design, material composition, and other external factors affecting building performance, prediction of the service life for a building or its components is seldom unanimous. The Army classifies facilities as permanent, semipermanent, and temporary. In addition, a facility belongs to one of the specific investment categories shown in Table 2. This situation has caused confusion to the point that all research into facility management has lost its generality and invited common-sense criticisms of simulation models for practical application. Another problem in this research field is that past facility investment in the U.S. Army fluctuated greatly, due in part to war involvement or changes in defense policy.

Despite these circumstances, a decision-maker is always required to make relatively knowledgeable decisions. The research to date into real property management has made significant gains such as identifying M&R funding requirements, analyzing life-cycle costs of facilities,[1] and constructing a framework for building research.[2] Simplifying the actual decision environment and sacrificing certain specifics are sometimes unavoidable. However, appropriate simulation models can maximize the realism in making decisions on facility renewal/replacement.

Objective

The objective of this study was to develop simulation models that encompass realistic factors of facility renewal. Successful models will:

1. Provide a clear understanding of facility cost behavior.
2. Evaluate alternative management strategies of facility replacement.
3. Predict future cost requirements for M&R and replacement.
4. Aid in estimating the average economic life and average age of facilities.

[1] R. D. Neathammer, *Life-Cycle Cost Data Base Design and Sample Data Development*, Interim Report P-120/ADA097222 (U.S. Army Construction Engineering Research Laboratory [USA-CERL], 1981).

[2] Osman Coskunoglu and Alan W. Moore, *An Analysis of the Building Renewal Problem*, Technical Report P-87/11/ADB112755 (USA-CERL, 1987).

Table 1

Degradation Factors Affecting the Service Life of Building Components and Materials*

Weathering Factors

- Radiation
  - Solar
  - Nuclear
  - Thermal
- Temperature
  - Elevated
  - Depressed
  - Cycles
- Water
  - Solid (e.g., snow, ice)
  - Liquid (e.g., rain, condensation, standing water)
  - Vapor (e.g., high relative humidity)
- Normal air constituents
  - Oxygen and ozone
  - Carbon dioxide
- Air Contaminants
  - Gases (e.g., oxides of nitrogen and sulfur)
  - Mists (e.g., aerosols, salt, acids, alkalies dissolved in water)
  - Particulates (e.g., sand, dust, dirt)
- Freeze-thaw
- Wind

Biological Factors

- Microorganisms
- Fungi
- Bacteria

Stress Factors

- Stress, sustained
- Stress, periodic
  - Physical action of water as rain, hail, sleet, and snow
  - Physical action of wind
  - Combined physical action of water and wind
  - Movement due to other factors, such as settlement or vehicles

Incompatibility Factors

- Chemical
- Physical

Use Factors

- Design of system
- Installation and maintenance procedures
- Normal wear and tear
- Abuse by the user

*Source: Geoffrey Frohnsdorff and L. W. Masters, "The Meaning of Durability Prediction," *Durability of Building Materials and Components*, ASTM STP 691, P. J. Sereda and G. G. Litvan (Eds.) (American Society for Testing and Materials [ASTM], 1978), p 23. ©ASTM. Reprinted with permission.

Table 2

Facility Investment Categories*

Operational facilities
Communication/aviation facilities
Aviation operational facilities
Harbor and coastal facilities
Training facilities
Maintenance facilities
Production facilities
Research, development, test, and evaluation facilities
Petroleum, oil, and lubricant (POL) supply facilities
Ammunition supply facilities
Other supply facilities
Hospital and medical facilities
Administrative facilities
Family housing
Unaccompanied family housing
Community facilities
Utility facilities
Roads and grounds

*Source: *Replacement Cost - United States and Overseas* (Facility Engineering Support Agency, 1986).

Approach

Simulation models were developed which consider a facility as an assembly of independent components. There are two major input variables: (1) the service life of an individual facility component and (2) its replacement cost.

The service life of each component was generated by a Weibull distribution. A component is replaced at the time of failure which is considered as an epoch of M&R for a facility. The cost of component replacement was estimated by its original construction cost, and this figure was adjusted upward to the original construction cost to account for the additional labor and possible damage caused to other, adjacent components. The M&R cost of a facility was considered to be the result of successive failures of respective components. By applying these factors, three simulation models were developed to successively: (1) estimate M&R cost by the facility's age, (2) evaluate replacement strategies, and (3) predict future cost requirements of the facility.

Mode of Technology Transfer

If these simulation models prove successful in predictions for a variety of Army facilities, they will be recommended as alternatives to the current methods of estimating operating and M&R costs.

2 SIMULATION MODELS: FOUNDATION AND DEVELOPMENT METHOD

In the developmental phase of this study, three simulation models that have identical basic structures, with minor modifications, evolved in sequence. Figure 1 shows the model development procedures. From this approach, a basic framework was formed. The resulting simulation models (I through III in Figure 1) are described in detail later in this chapter.

Framework

A facility consists of replaceable and nonreplaceable components. The lifespans of replaceable components may be shorter than the life of the facility whereas those of nonreplaceable components may be as long as the facility's life. As an example, foundations and framing might be classified as nonreplaceable components, with roofing, doors, and windows considered replaceable components. For simplicity, the costs of minor repair and routine maintenance are ignored; the replacement of a replaceable component is assumed to be a major cause of cost incurrence for facility M&R. In other words, the history of M&R costs for a facility is assumed merely as a record of replacement cost of the individual replaceable components. Hence, the model requires two kinds of basic data: life length and replacement cost for each component.

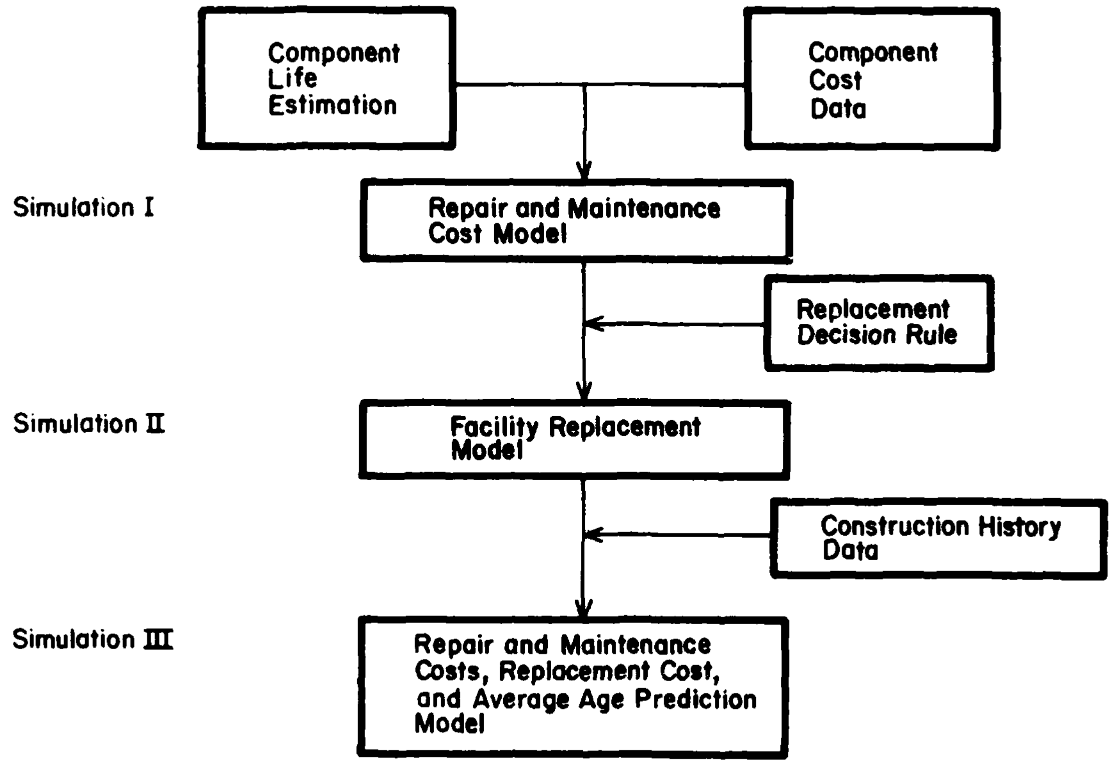

Figure 1. Model development procedure.

Component Life

The time it takes a living thing or piece of equipment to fail is probabilistic by nature. Even describing the state of failure is ambiguous and sometimes very subjective. Hence, defining the failure state of components is useful in describing failure of the overall facility. Since minor repair requirements are not considered in this study, the scope of the problem can be narrowed by adopting the following definition: "The state of failure of a component is the state for which the long-run cost efficiency of a facility is best achieved by replacing the component."

The lifetime of a component was estimated in three ways: (1) longest (or optimistic) life, (2) most likely life, and (3) shortest (or pessimistic) life. This three-way life estimation is a basis for determining a particular shape of time-failure curve (Weibull distribution) for a component.

Weibull Distribution

The empirical Weibull distribution appears to fit a large number of failure characteristics for equipment.[3] The Weibull family is one of the continuous random variables for which the density functions are positive over all positive reals.[4]

Bekker applied the Weibull distribution as a time-to-failure model and found a significant correlation between the cumulative distribution of both demolished and withdrawn dwellings with the theoretical curve of a cumulative Weibull distribution.[5] Martin recommended the Weibull distribution to predict building material service life and provided references giving results of Weibull applications.[6]

The Weibull distribution results from the hazard function:

$$h(t) = \frac{\eta}{\sigma} \left(\frac{t}{\sigma}\right)^{\eta-1} \qquad \text{[Eq 1]}$$

where σ is the scale parameter and η is the shape parameter. The hazard function gives the probability of failure during a very small time increment, assuming no failure occurred before that time (t):

$$h(t) = \frac{f(t)}{1 - F(t)} \qquad \text{[Eq 2]}$$

where f(t) and F(t) are the probability density and distribution functions for time to failure, respectively.

---

[3]A. K. S. Jardine, *Maintenance, Replacement, and Reliability* (John Wiley and Sons, 1973).

[4]G. A. Mirham, *Simulation* (Academic Press, 1972).

[5]P. C. F. Bekker, "Influence of Durability on Material Consumption and Strategy of Building Industry," *Durability of Building Materials and Components*, Proceedings of the First International Conference, P. J. Sereda and G. G. Litvan (Eds.) (ASTM, August 1978).

[6]J. W. Martin, "Time Transformation Functions Commonly Used in Life Testing Analysis," *Durability of Building Materials and Components*, Proceedings of the First International Conference, G. Frohnsdorff and B. Horner (Eds.) (National Bureau of Standards, September 1981).

The probability density function of the Weibull distribution is:

$$f(t) = \begin{cases} \frac{\eta}{\sigma} \left(\frac{t-\gamma}{\sigma}\right)^{\eta-1} \exp\left[-\left(\frac{t-\gamma}{\sigma}\right)^{\eta}\right], & t \geq \gamma,\ \sigma > 0,\ \eta > 0 \\ 0 & \text{elsewhere} \end{cases} \qquad \text{[Eq 3]}$$

where σ is the scale parameter, η is the shape parameter, and γ is the location of the origin. The hazard function and the probability density function for the Weibull distribution have a wide variety of shapes, as can be seen from the plots for different values of η in Figures 2 and 3. In particular, when $\eta > 1$, the Weibull probability density function is single-peaked and the hazard function increases with t; for $\eta < 1$, the probability density function is reverse-J-shaped and the hazard function decreases with t. When $\eta = 1$, the hazard function is a constant and the Weibull distribution is equivalent to the exponential distribution.

The cumulative Weibull distribution is:

$$F(t) = \int_0^t \frac{\eta}{\sigma} \left(\frac{y-\gamma}{\sigma}\right)^{\eta-1} \exp\left[-\left(\frac{y-\gamma}{\sigma}\right)^{\eta}\right]dy = 1 - \exp\left[-\left(\frac{t-\gamma}{\sigma}\right)^{\eta}\right],\ t \geq \gamma \qquad \text{[Eq 4]}$$

The statistical theory supporting the Weibull distribution or a time-to-failure model is described in detail by Hahn and Shapiro[7] and Mann, et al.[8]

Parameter Estimation of Weibull Distribution

For 'his estimation:

let t_s = shortest life of a component i
t_m = most likely life of a component i
t_ℓ = longest life of a component i.

Probability density function (pdf) of the Weibull distribution is:

$$f(t) = \begin{cases} \frac{\eta}{\sigma} \left(\frac{t-\gamma}{\sigma}\right)^{\eta-1} \exp\left[-\left(\frac{t-\gamma}{\sigma}\right)^{\eta}\right], & t \geq \gamma,\ -\infty < \gamma < \infty,\ \sigma > 0,\ \eta > 0 \\ 0 & \text{elsewhere} \end{cases}$$

where:

σ = scale parameter of a component i
η = shape parameter of a component i
γ = location of origin of a component i.

[7] G. H. Hahn and S. S. Shapiro, *Statistical Models in Engineering* (John Wiley and Sons, 1967).
[8] N. R. Mann, R. E. Schafer, and N. D. Singpuwalla, *Methods for Statistical Analysis of Reliability and Life Data* (John Wiley and Sons, 1974).

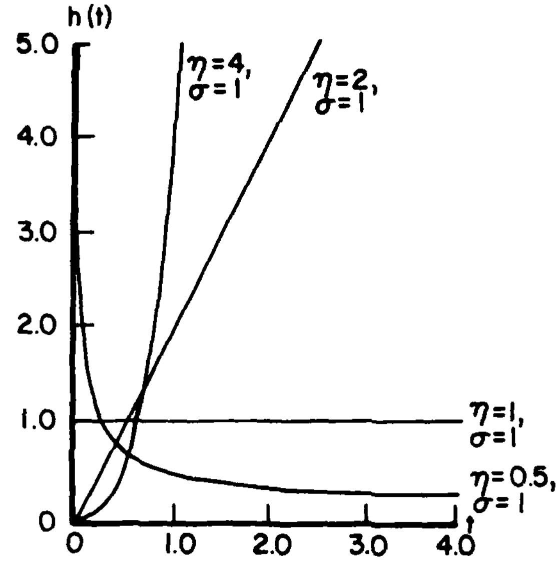

Figure 2. Hazard functions for Weibull distribution with $\sigma = 1$ and various values of η.

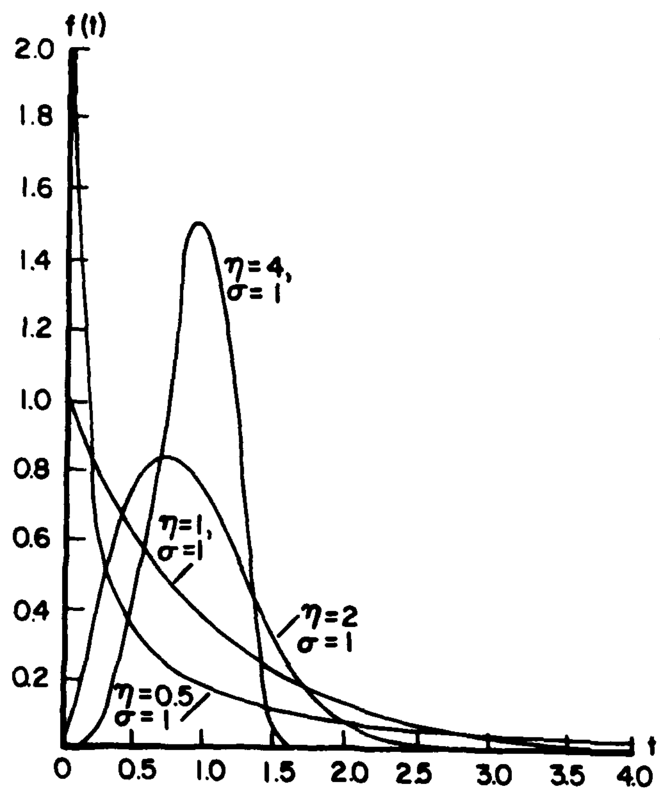

Figure 3. Weibull distributions for $\gamma = 0$, $\sigma = 1$, and various values of η.

Since $\gamma = t_s$ and t_m is the peak of pdf, the pdf shape of the Weibull distribution is as shown in Figure 4.

At the peak of pdf, $\frac{df}{dt} = 0$; that is:

$$\frac{df(t)}{dt} = \frac{\eta}{\sigma}(\eta-1)\left(\frac{t-\gamma}{\sigma}\right)^{\eta-2} \cdot \frac{1}{\sigma} \exp\left[-\left(\frac{t-\gamma}{\sigma}\right)^{\eta}\right] +$$

$$\frac{\eta}{\sigma}\left(\frac{t-\gamma}{\sigma}\right)^{\eta-1} \cdot \eta \left(\frac{t-\gamma}{\sigma}\right)^{\eta-1} \cdot \left(-\frac{1}{\sigma}\right) \exp\left[-\left(\frac{t-\gamma}{\sigma}\right)^{\eta}\right] = 0$$

Since the change of origin does not affect the shape of pdf (i.e., values of σ and η are independent of γ) it is possible to let $\gamma = 0$ without loss of generality. At $t = t_m$:

$$(\eta-1)\left(\frac{t_m}{\sigma}\right)^{\eta-2} = \eta\left(\frac{t_m}{\sigma}\right)^{\eta+(\eta-2)}$$

or:

$$\left(\frac{t_m}{\sigma}\right)^{\eta} = \frac{\eta-1}{\eta} \qquad \text{[Eq 5]}$$

The probability distribution function of the Weibull distribution is:

$$F(t) = 1 - \exp\left[-\left(\frac{t-\gamma}{\sigma}\right)^{\eta}\right]$$

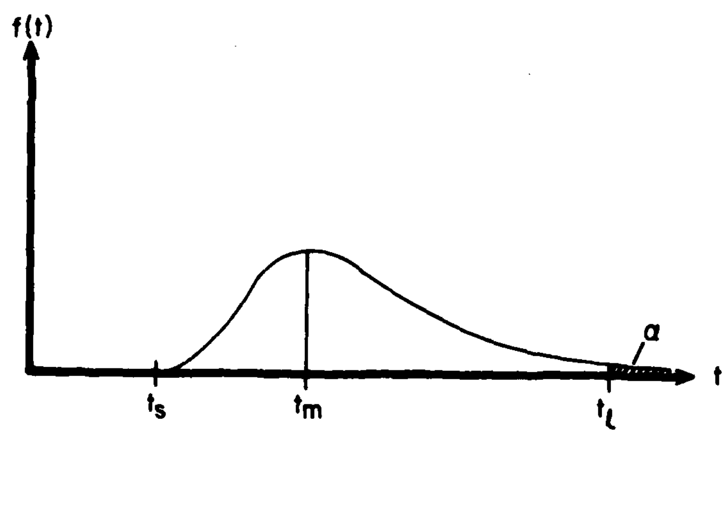

Figure 4. Probability density function of the Weibull distribution.

By limiting the size of the right tail of the pdf (shaded area in Figure 4) to α and again making $\gamma = 0$:

$$F(t_\ell) = 1 - \exp\left[-\left(\frac{t_\ell}{\sigma}\right)^\eta\right] = 1 - \alpha$$

Hence:

$$-\left(\frac{t_\ell}{\sigma}\right)^\eta = \text{Ln}\ \alpha \qquad \text{[Eq 6]}$$

Equations 5 and 6 are nonlinear simultaneous equations with two variables. Therefore, σ and η are determined if t_m and t_ℓ are given. For $\alpha = 0.01$:

$$\eta \text{Ln} t_m - \eta \text{Ln} \sigma = \text{Ln}(\eta - 1) - \text{Ln} \eta \qquad \text{[Eq 7]}$$

$$\eta \text{Ln} t_\ell - \eta \text{Ln} \sigma = \text{Ln} 2 + \text{Ln}\ (\text{Ln} 10) \qquad \text{[Eq 8]}$$

From Equations 7 and 8, an equation of η can be derived:

$$\eta \text{Ln}\ (t_\ell / t_m) - \text{Ln} \eta + \text{Ln}(\eta - 1) = \text{Ln} 2 + \text{Ln}\ (\text{Ln} 10) \qquad \text{[Eq 9]}$$

Equation 9 is easily solvable by the numerical method and σ is obtained by substitution.

Generation of a Component's Replacement Cycle

Let U = a pseudorandom number. For the Weibull distribution function, let:

$$F(t) = 1 - \exp\left[-\left(\frac{t-\gamma}{\sigma}\right)^\eta\right] = U \qquad \text{[Eq 10]}$$

or:

$$-\left(\frac{t-\gamma}{\sigma}\right)^\eta = \text{Ln}\ (1-U) \qquad \text{[Eq 11]}$$

Therefore, the life of a component is:

$$t = \gamma + \sigma\ [-\text{Ln}\ (t-U)]^{1/\eta} \qquad \text{[Eq 12]}$$

Cost Estimation of Component Replacement

New construction cost of a facility is used as a basis for estimating the replacement cost of a component. The new construction cost of a component is adjusted by considering additional labor and/or possible damage to adjacent components during repair activities. For example, painting an old facility might require scraping the old paint off; or, replacing the duct system for heating and air-conditioning may damage the floor or ceiling.

Generation of a Component's Replacement Cost

In this study, ±10 percent variation is allowed in the replacement cost of a component. The component replacement cost varies uniformly within this range.

Let U = a pseudorandom number

R = average replacement cost of a component i

Then, the replacement cost of a component i is:

$$C = 0.9R + 0.2R \times U$$

Facility Replacement Criteria: Relative Repair Cost

A component of a facility might be functioning poorly or deteriorating rapidly in the later stages of its life before it actually fails. Such a component is defined as a "marginal component." A period of state as a marginal component is termed the "marginal period" of a component. The length of a marginal period for each individual component is assumed to be the last quarter of its life; i.e., the last 25 percent of its life length.

A facility is replaced if there are many marginal components and replacement of those components would require a high expenditure. As a criterion of facility replacement, the concept of relative repair cost can be introduced. "Relative repair cost (RRC)" of a facility is the ratio between repair cost and restored value. "Restored value" is a current (market) value when marginal components are completely repaired. Thus:

$$RRC = \frac{\text{Repair cost of marginal components}}{\text{Restored value}} \qquad \text{[Eq 13]}$$

In considering the replacement of operational equipment of a production facility, M&R cost of an object usually is not compared with its market value.[9] The basic difference between a production facility and a real property facility in a replacement decision might be the conceptual difference between use value and exchange value. A production facility is a means to produce a certain end-product. Since the purpose of a production facility is not for exchange but for production, the exchange value of the facility has no meaning. As long as the output maintains required objective quality standards, use value of a facility remains the same. Hence, M&R and new facility investment costs are adequate for determining replacement. On the other hand, a real property facility is not only an end-product that should satisfy various needs of a user, but also an exchangeable product as are other commodities that can be sold on the market. The effect of an activity given to the facility should be measured by the resulting gain or loss in exchange value.

If the relative repair cost sum of a facility exceeds a critical number (CR), the facility is replaced at the time when the first failed component is found among the

[9]A. K. S. Jardine.

marginal components as shown in Figure 5. Otherwise, a component is replaced individually at the time of its failure.

Relative Repair Cost Measure: Implication as a Replacement Criterion

When a production facility or real property facility is replaced, the following relationship should hold at the time of replacement:

$$\begin{pmatrix}\text{Immediate repair}\\ \text{cost savings by}\\ \text{replacement}\end{pmatrix} + \begin{pmatrix}\text{Future repair}\\ \text{cost savings by}\\ \text{replacement}\end{pmatrix} + \begin{pmatrix}\text{Value difference}\\ \text{from new facility}\\ \text{to current facility}\end{pmatrix} \geq \begin{pmatrix}\text{New}\\ \text{facility}\\ \text{cost}\end{pmatrix}$$

As was mentioned earlier, the value of a production facility might be measured by its use value. There is no value difference between a new production facility and the current one in the above relationship since the use values of both facilities are considered the same.

For a real property facility, the value might be measured by its exchange (i.e., market) value. Hence, the third term in the above relationship:

$$\begin{pmatrix}\text{Value difference}\\ \text{from new facility}\\ \text{to current facility}\end{pmatrix} = \begin{pmatrix}\text{New facility}\\ \text{market value}\end{pmatrix} - \begin{pmatrix}\text{Current facility}\\ \text{market value}\end{pmatrix}$$

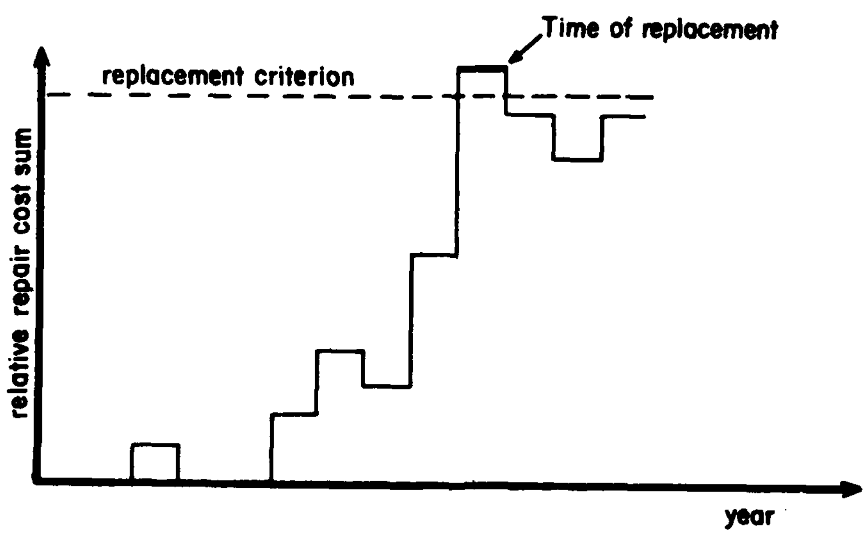

Figure 5. Method of replacement.

If it is assumed that market value of a new facility is equal to the cost of the facility, the following relationship holds for the replacement of a real property facility:

$$\left(\begin{array}{c}\text{Immediate repair cost}\\ \text{savings by replacement}\end{array}\right) + \left(\begin{array}{c}\text{Future repair cost}\\ \text{savings by replacement}\end{array}\right) \geq \left(\begin{array}{c}\text{Current facility}\\ \text{market value}\end{array}\right)$$

Dividing the left-side terms by the right-side term above:

$$\left(\begin{array}{c}\text{Immediate relative}\\ \text{repair cost savings}\\ \text{by replacement}\end{array}\right) + \left(\frac{\text{Future repair cost savings by replacement}}{\text{Current facility market value}}\right) \geq 1$$

The first term in the above relationship was applied as the replacement criterion in this report. Since the relative repair cost measure compares repair cost with the market value of a facility, the benefit of adopting this measure as a replacement criterion is that it can indirectly reflect functionality and design, as well as physical condition, of a facility.

Long-Run Average Relative Facility Cost

Long-Run Average Facility Cost (LAFC) is defined as an annual average cost of a facility for its construction and M&R during the service life. Thus:

$$\text{LAFC} = (\text{Probability of life length}) \times \frac{(\text{Lifetime total repair cost + construction cost})}{(\text{life length})} \qquad \text{[Eq 14]}$$

A similar definition can be introduced by substituting repair cost with relative repair cost (or long-run average relative facility cost--LARFC) as follows:

$$(\text{LARFC}) = (\text{Probability of life length}) \times \frac{(\text{Lifetime total relative repair cost + 1})}{(\text{Life length})} \qquad \text{[Eq 15]}$$

Relative repair cost might implicitly consider the qualitative aspect of a facility. In this study, LARFC was applied as an optimal criterion for evaluating replacement decision rules.

Simulation Model I: M&R Cost Model

The purpose of the first simulation model is to investigate the behavior of M&R costs of a group of facilities in a facility investment category. A facility is considered to be a set of replaceable and nonreplaceable components. The failure of replaceable components is the cause of M&R costs. The failure of a component is generated by a Weibull random-number generator and the M&R cost is obtained by a uniform random-number generator. Inputs to the simulation are three-way life estimation data and construction cost data of each component. Simulation model output is the ratio of the annual average M&R cost to the replacement cost of a facility in percent. Figure 6 is a flowchart of simulation model I.

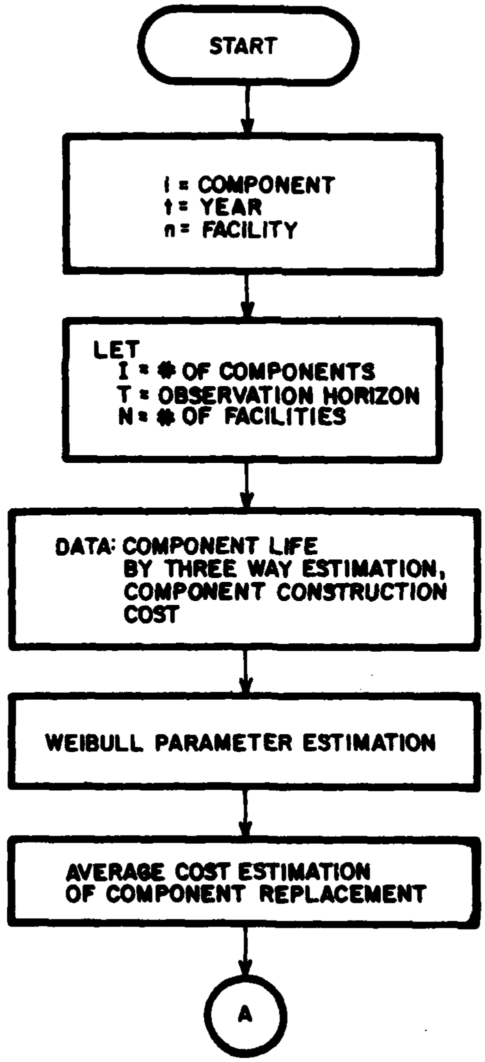

Figure 6. Simulation model I flowchart.

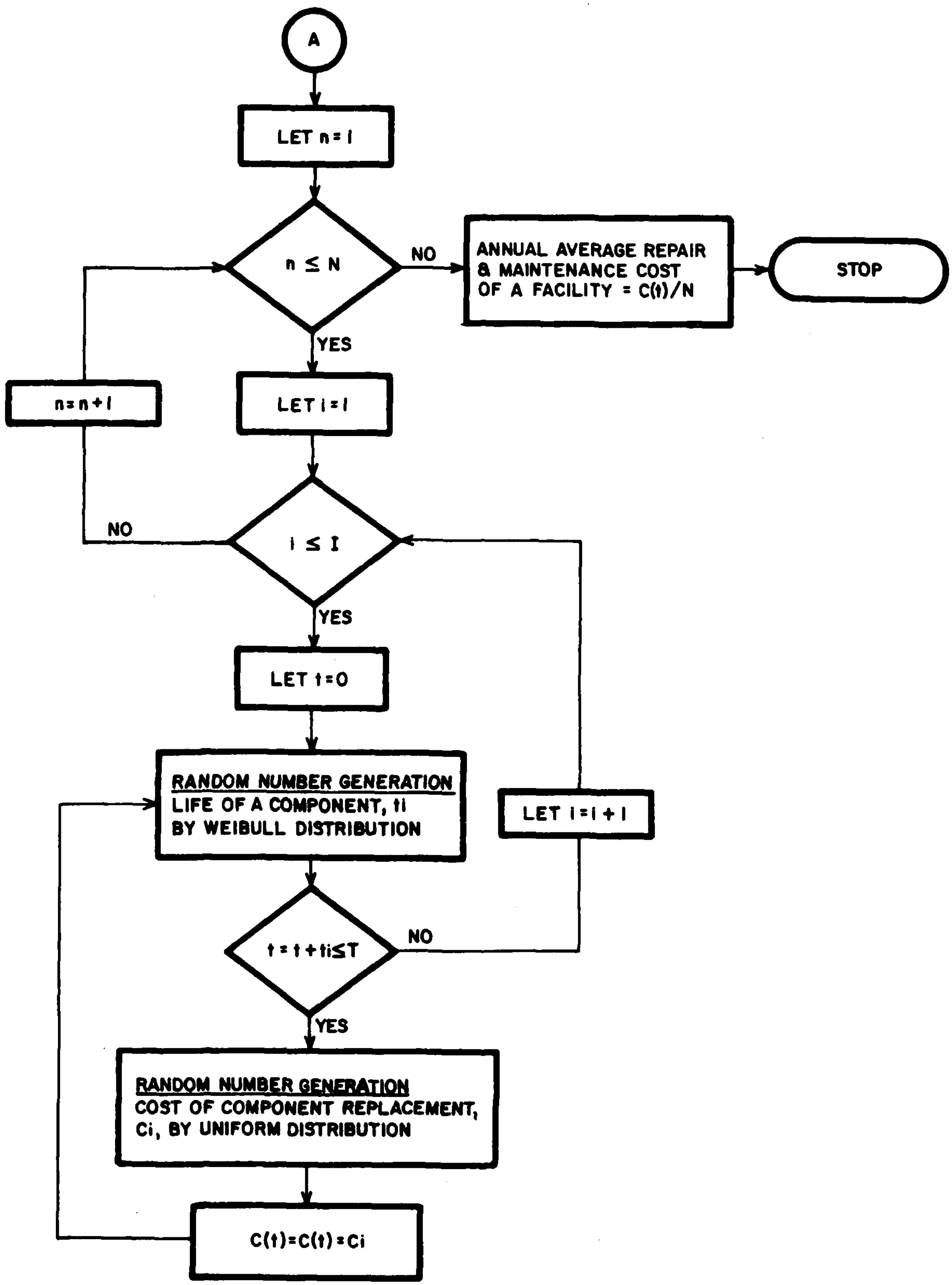

Figure 6. (Cont'd)

Simulation Model II: Replacement Decision Model

The purpose of this model is to examine the aggregate cost of facilities' M&R and replacement over the long run by adopting a certain replacement decision value. Several different relative repair cost criteria are compared.

Inputs to the model are the same as in simulation model I. Outputs of the simulation are the probability of facility replacement by age, expected life of a facility, and ratio of the long-run annual average cost to the replacement cost of a facility for the respective replacement decision rule. Relative repair cost criteria for replacement decisions are examined. Absolute repair cost criteria, which are measured as a percentage of the replacement cost of a facility, are also shown as a reference to the relative repair cost criteria. Figure 7 is a flowchart of this model.

Simulation Model III: Facility Management Cost Prediction Model

An organization's inventory of facilities has a certain profile in terms of construction year and spatial quantity. Simulation model III was developed to predict the future cost trends of M&R and facility replacement using realistic inventory data.

A replacement decision rule is specified as an input along with the inputs of simulation I for the run of this model. Outputs of the model are the facility management cost and the average age of facilities in future years. Figure 8 is a flowchart for this model.

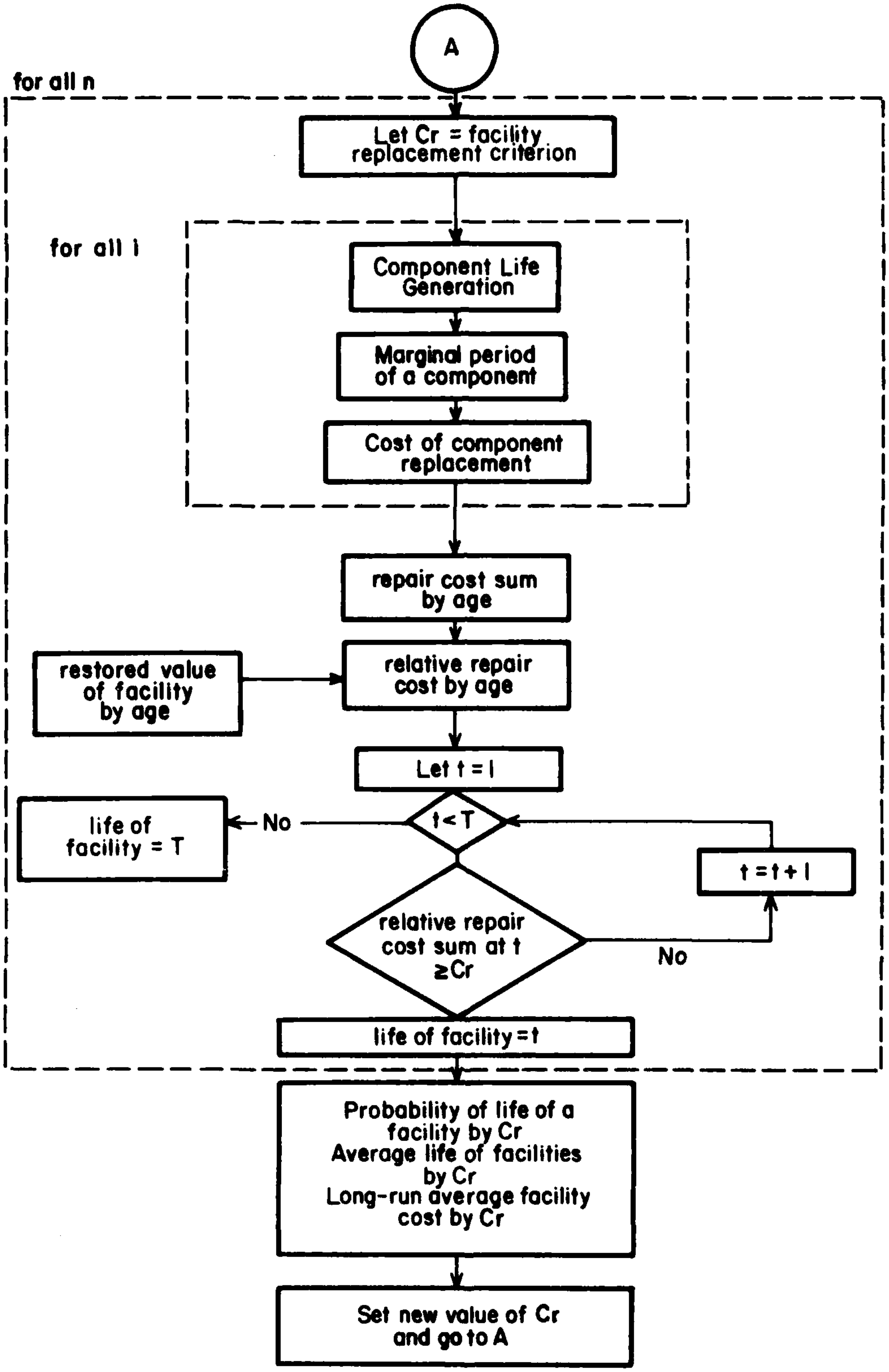

Figure 7. Simulation model II flowchart.

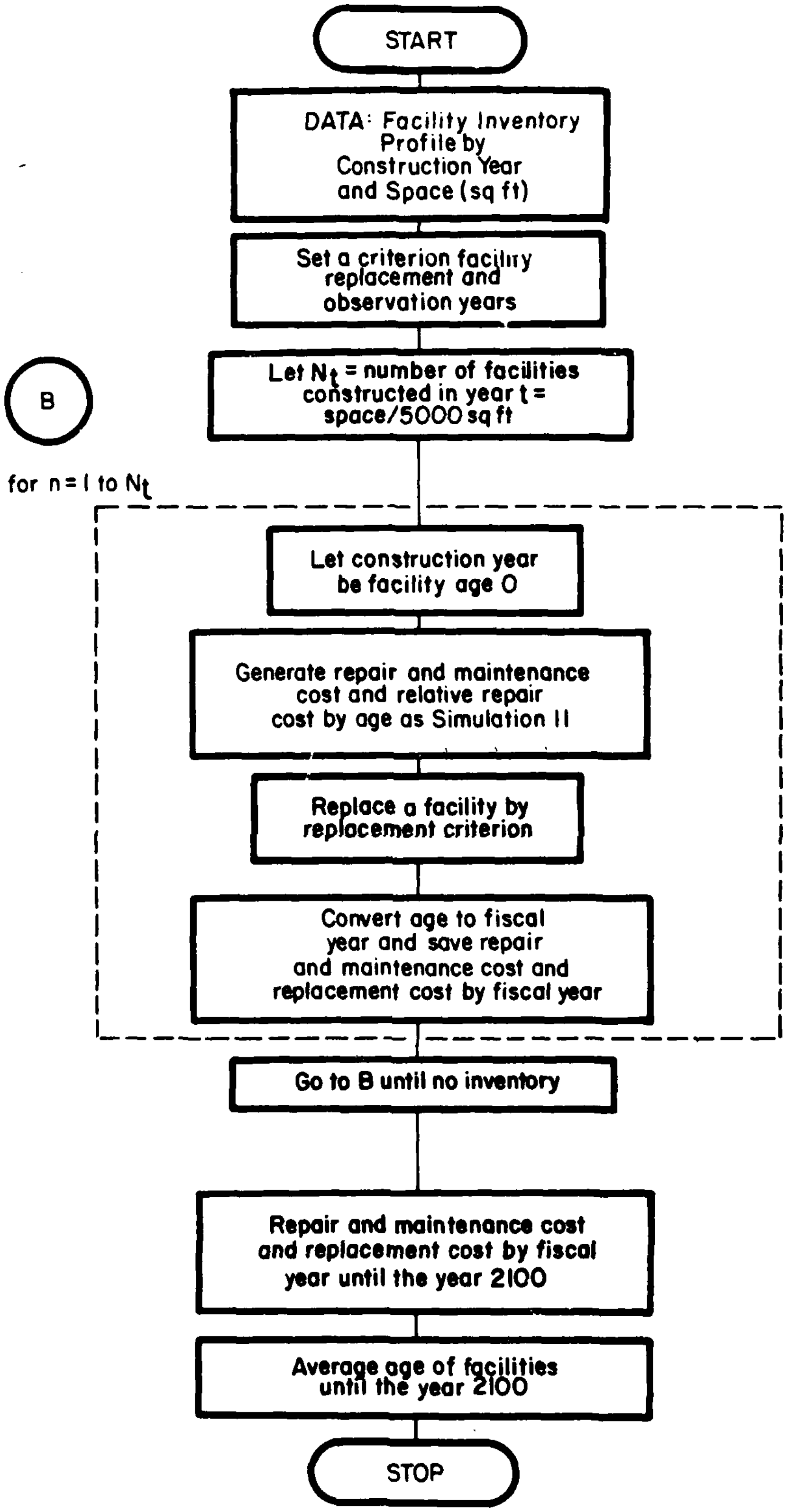

Figure 8. Simulation model III flowchart.

3 SIMULATION MODELS APPLICATION: FAMILY HOUSING

The simulation models developed in this study implicitly assume that facilities are alike in terms of their components' lives and construction costs. However, this assumption might be too risky if the model is applied without discretion to all categories of building facilities in the Army.

As an example of implementing the models, the family housing category was chosen. Family housing recently received one-quarter of the Army's facilities management budget. To run simulation models I and II, two sets of data are needed: (1) three-way life estimation of components and (2) construction costs of components. Simulation III requires data sets 1 and 2 above, along with the inventory record of family housing by construction years and spatial quantity to predict future family housing management costs.

Component Construction Cost Data

The construction cost of a component was obtained from *Residential/Light Commercial Cost Data, 1987*, 6th annual ed. (R. S. Means Co.). Family housing in the Army was assumed to be low-cost facilities. The cost data were averaged for economy 1-story, 1-1/2-story, and 2-story housing from the above source. Since component differentiation in this source is not precise, for the purpose of the simulation model, some components were further subdivided and costs were detailed in terms of labor and material by considering the composition of a component. The costs for site work and contractor's overhead at the time of construction were not considered. The cost of each component is shown in Table 3.

Replacement Cost of a Component

As mentioned earlier, repair work for a component occasionally requires more labor than did the original construction and/or damaged adjacent components. Hence, the replacement cost of a component should consider these side-effects and adjust the original construction cost to reflect these additional costs. The cost increment for replacement of a component was obtained by the detailed analysis of material and labor cost data in *Residential/Light Commercial Cost Data, 1987*, and reviewed by specialists at the U.S. Army Construction Engineering Research Laboratory (USA-CERL). The result is shown in Table 4.

Three-Way Life Estimation of Components

As mentioned in Chapter 2, life length of a component was assumed following the Weibull distribution. To specify the shape of the Weibull distribution function for each component, life length of the component was first measured by shortest life, followed by most likely life, and then longest life. The life estimation data were obtained from

Table 3

Component Cost of Family Housing

Component	Contents	Cost per sq ft ($)
<u>Nonreplaceable</u>		
1. Foundations and structures	Excavation, piling, columns, load-bearing and shear walls or bracing, floor slabs, beams, and girders above grade	9.41
<u>Replaceable</u>		
2. Roofing	Roofs, flashing, guttering, downspouts	1.25
3. Exterior cladding	Skylights, nonstructural skin, insulation	2.66
4. Exterior doors and windows	Doors and windows	3.96
5. Exterior finishes	Paint, calk, other finishes	0.90
6. Interior partitions	Non-load-bearing walls, ceilings, sound insulation	4.82
7. Interior doors and windows	Doors and windows	1.28
8. Interior finishes	Floor coverings, plaster work, trim, drapes, paint, light fixtures	4.90
9. Mechanical (moving)	Fans, heating and cooling coils, motors, cooling towers	1.90
10. Mechanical (static)	Plumbing system, ductwork, diffusers, registers	1.90
11. Electrical	Switches, relays, circuit breakers, fuses, wiring	0.85
12. Special equipment	Built-in appliances, cabinet work, special work areas	0.97

Table 4

Replacement Cost of a Component

Component	Cost Increase by Additional Labor	Cost Increase by Damaging Other Components
Roofing	10% of original construction	None
Exterior cladding	10%	100% of exterior finishes 5% of electrical
External doors and windows	5%	5% of exterior finishes 5% of interior finishes
Exterior finishes	50%	5% of electrical
Interior partitions	None	35% of interior finishes 15% of electrical
Interior doors and windows	None	None
Interior finishes	None	None
Mechanical (moving)	None	None
Mechanical (static)	30%	15% of interior partitions 3% of interior finishes
Electrical	None	5% of interior partitions 1% of interior finishes
Special equipment	None	5% of interior partitions 1% of interior finishes 2% of mechanical (static) 2% of electrical

several sources[10] and reviewed by USA-CERL specialists. Table 5 lists results of the estimation and the Weibull parameters. The Weibull parameters in the table are numerical solutions of Equation 9 in Chapter 2.

Identical Components in Life Length

If several components have the same life length, these components could be considered as one component for the simulation run. However, special care was taken in identifying the replacement cost of other components for this study since the construction cost of the component affects the replacement cost of other components.

In Table 5, interior finishes with vinyl or wood floor components show the same life length as the special equipment component. Since the estimated cost of floor per square foot of housing was \$1.50, and the carpeted floor is two-thirds of the floor space while the uncarpeted floor is one-third of the floor space, the cost of vinyl or wood floor per square foot of housing is \$0.50. Hence, \$0.50 was deducted from the interior finishes component and the same amount was added to the special equipment component in Table 3. The construction costs of the interior finishes component and the special equipment component are \$4.40 and \$1.47, respectively.

Simulation Model I Results

M&R cost was measured as a percentage of the facility's net replacement cost. Net replacement cost of a facility is the construction cost of the facility, excluding the cost of site work and contractor's overhead.

The computer program used in the study and the output of the simulation using a Compaq 286 are given in Appendix A. Input data are from Tables 3 through 5. The expected M&R cost of a facility by age is shown in Figure 9. This graph shows that the expected cost of M&R fluctuates by age. After heavy repair around age 55, the M&R cost drops and begins a new repair cycle. This result implies that adopting average age as an independent variable might be erroneous for estimating annual M&R cost requirements. The linear expression of M&R cost by age might be valid at best within the interval of a major repair cycle.

---

[10] S. E. Pihlajavaara, "Background and Principles of Long-Term Performance of Building Materials," *Durability of Building Materials and Components*, ASTM STP 691, P. J. Sereda and G. G. Litvan (Eds.) (ASTM, 1978), pp 5-16; Ranko Bon, "Replacement Simulation Model (RSM): A Framework for Policy Decisions," unpublished paper (Department of Architecture, Massachusetts Institute of Technology, 1984); S. Janicki and St. Zaleski, "Bases for Maintenance, Repair and Modernization of Buildings," *Renewal, Rehabilitation and Maintenance*, Vol 16, CIB 23 (The National Swedish Institute for Building Research, 1983), pp 187-192.

Table 5

Life Estimation and Weibull Parameters*

Component	Shortest Life (t_s, γ) (yr)	Most Likely Life (t_m) (yr)	Longest Life (t_ℓ) (yr)	Scale Parameter (α)	Shape Parameter (η)
Roofing	10	25	35	3.7	16
Exterior cladding	30	50	70	2.9	23
Exterior doors and windows	30	60	100	2.5	36
Exterior finishes	15	20	25	2.9	5
Interior partitions	75	100	150	2.1	34
Interior doors and windows	40	75	125	2.4	43
Interior finishes** (vinyl or wood floor)	7 (10)	15 (30)	25 (50)	2.6 (2.9)	9 (23)
Mechanical (moving)	10	15	25	2.1	6
Mechanical (static)	30	50	80	2.3	25
Electrical	25	50	75	2.9	28
Special equipment	10	30	50	2.9	23

*Data were combined from the following sources: S. E. Pihlajavaara, "Background and Principles of Long-Term Performance of Building Materials," *Durability of Building Materials and Components*, ASTM STP 691, P. J. Sereda and G. G. Litvan (Eds.) (American Society for Testing and Materials, 1978), pp 5-16; Ranko Bon, "Replacement Simulation Model (RSM): A Framework for Policy Decisions," unpublished paper (Department of Architecture, Massachusetts Institute of Technology, 1984); S. Janicki and St. Zaleski, "Bases for Maintenance, Repair and Modernization of Buildings," *Renewal, Rehabilitation and Maintenance*, Vol 16, CIB 83 (The National Swedish Institute for Buildings Research, 1983), pp 187-192.

**Interior finishes with carpeted floor.

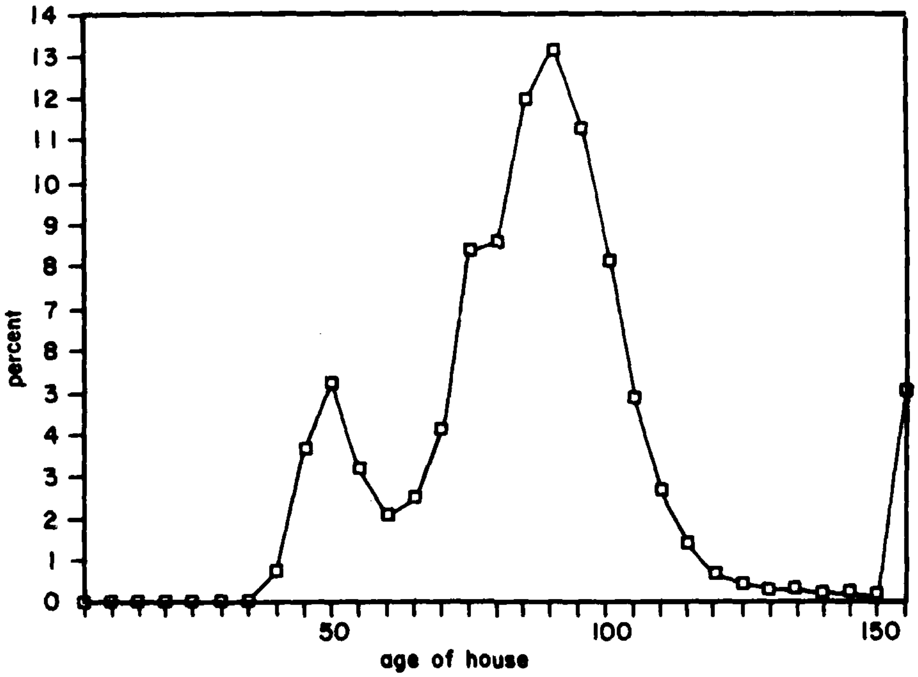

Figure 9. Average repair cost.

Simulation Model II Results

Relative repair cost is a percentage cost of M&R over the market value of a facility. As a proxy of the market value, the restored value was adopted; this value is the worth of a facility with no marginal components at all.

No depreciation of a replaceable component was considered as long as the component was not marginal. Complete linear depreciation was assumed for the nonreplaceable components up to 75 years of age of a facility. Hence, the restored value is the net replacement cost less depreciation. The 75-year depreciation period was chosen subjectively as a compromise between housing service lives of 60 years[11] and 88 years.[12] The restored value is shown in Figure 10.

If there are several marginal components and the sum of the relative cost exceeds a certain limit, the facility is replaced at the time when the first component failure is observed among the marginal components. Application of this replacement rule is shown in Figure 11. This graph demonstrates that adopting a low relative repair cost (RRC) sum as a replacement decision criterion recommends earlier replacement of a facility than adopting a high relative repair cost sum criterion. Figures 12 through 14 show the probability of replacement by age for the relative repair cost sums of 50, 55, and 60 percent, respectively.

---

[11] S. E. Pihlajavaara.
[12] Roger E. Cannaday and Mark A. Sudman, "Estimation of Depreciation for Single-Family Appraisals," ORER Paper 11 (Office of Real Estate Research, University of Illinois, Urbana-Champaign, 1985).

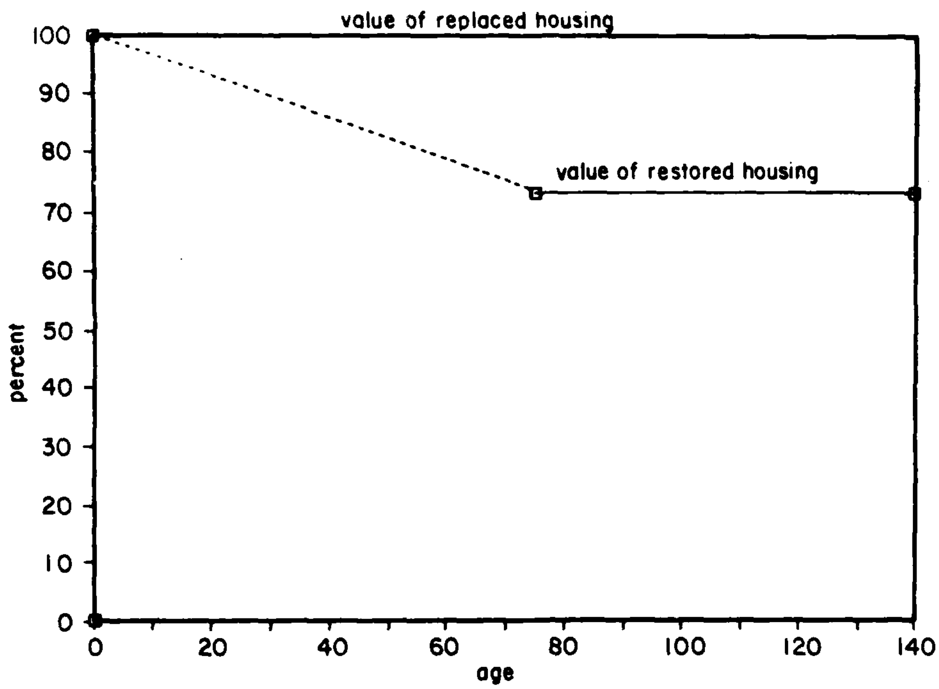

Figure 10. Value of restored housing.

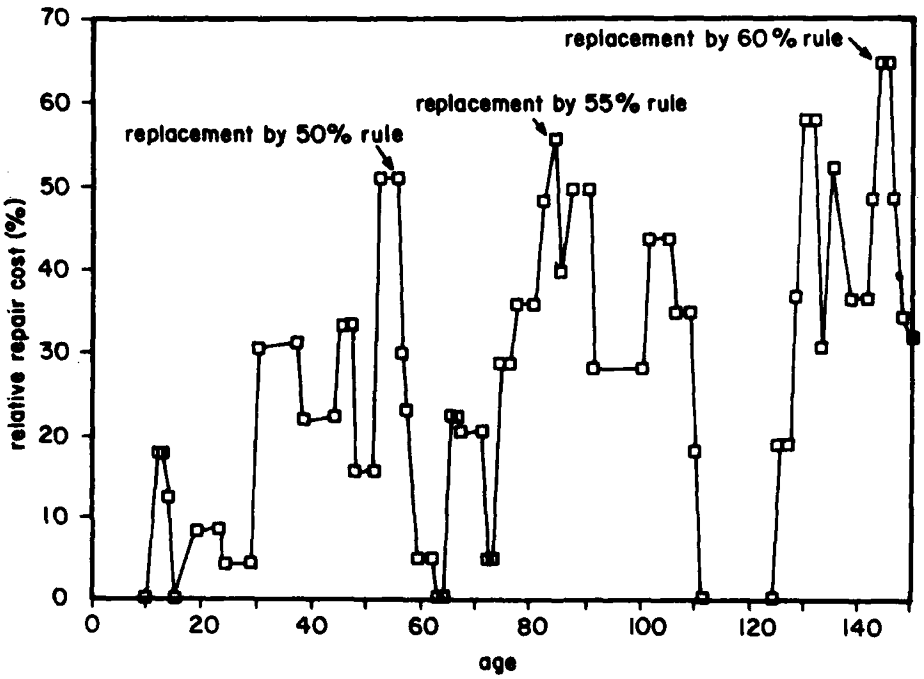

Figure 11. Relative repair cost sum by age.

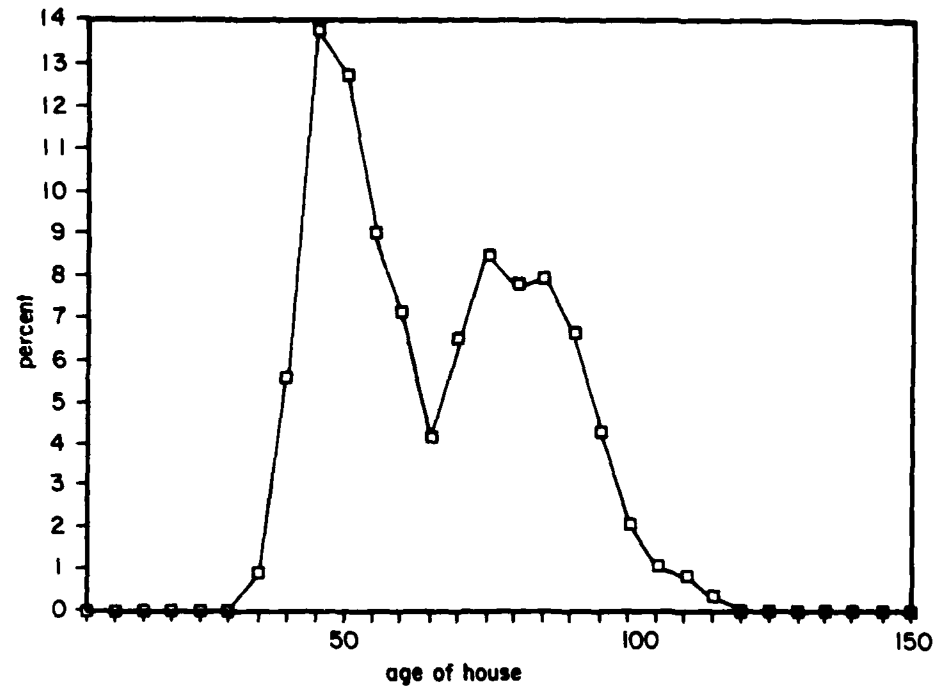

Figure 12. Probability of replacement for relative repair cost sum of 50 percent.

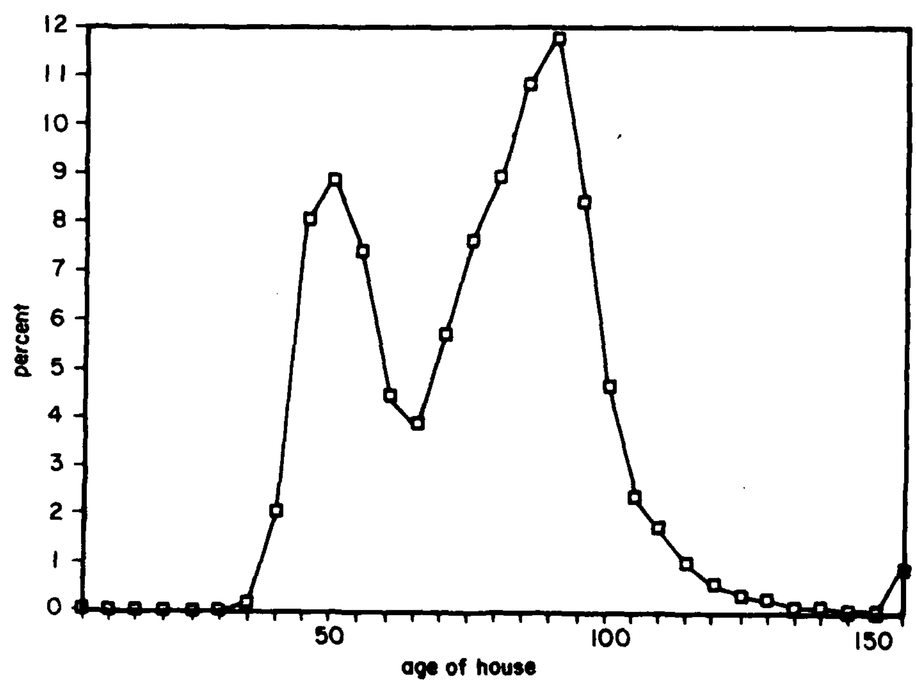

Figure 13. Probability of replacement for relative repair cost sum of 55 percent.

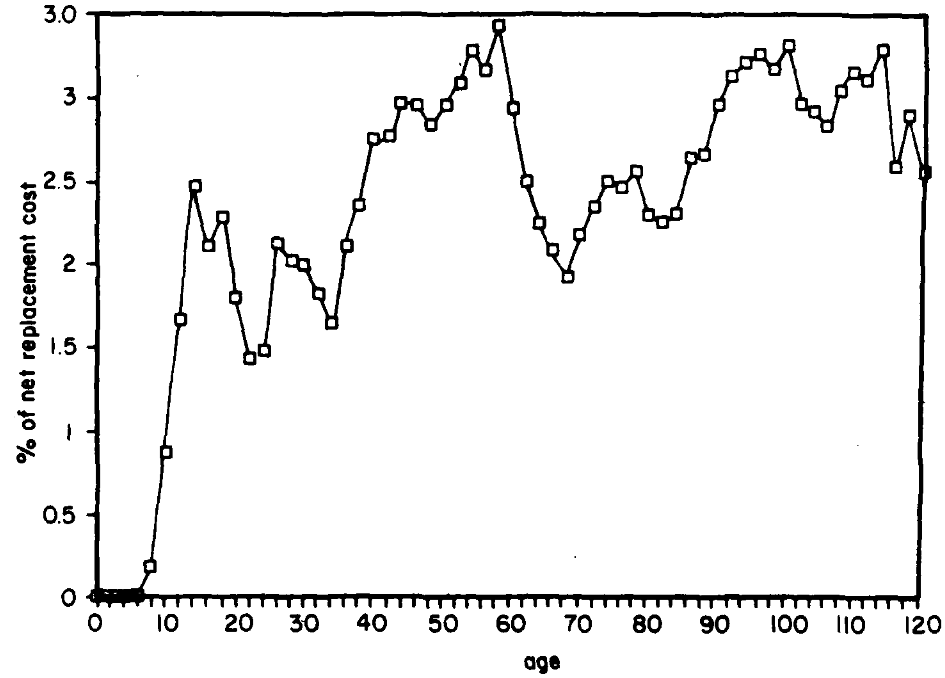

Figure 14. Probability of replacement for relative repair cost sum of 60 percent.

For a given maximum facility life, the LARFC is estimated for respective replacement criteria. For the maximum life of 100 to 150 years, the 60 percent of relative repair cost criterion is obtained as the long-run optimal value.

The computer program and the output results for the simulation II run are in Appendix B. The result of absolute repair cost criteria is included in the output. These results are summarized in Tables 6 and 7.

Simulation Model III Results

As was mentioned earlier, adopting the average age of facilities as a variable might be insufficient to estimate the M&R costs due to the fluctuation of these costs. In this simulation model, facility inventory data from FORSCOM and TRADOC by construction year and spatial quantity were obtained from the Integrated Facilities System (IFS) headquarters and used as additional input for the simulation.

Simulation model III generates the inventory profile for the MACOM and predicts the M&R and replacement costs up to the year 2100. The average age of family housing is also predicted. The computer programs and output for TRADOC are in Appendix C; those for FORSCOM are in Appendix D. To run the simulation, a replacement criterion must be input at the beginning of the program.

Figure 15 shows the family housing inventory profile of TRADOC by year of construction. More than 70 percent of family housing was built during 1950-70; more than one-third of this inventory was constructed during 1956-60.

Table 6

Long-Run Average Relative Facility Cost (LARFC)

Replacement Rule RRC Sum (%)	LARFC (%)* Maximum Life 100 Years	120 Years	150 Years
40	3.890	3.890	3.890
45	3.800	3.799	3.799
50	3.729	3.725	3.725
55	3.694	3.686	3.683
60	3.675*	3.664*	3.656*
65	3.698	3.686	3.666
70	3.723	3.718	3.689
100	3.835	3.867	3.796

*Optimal.

Table 7

Expected Life of Facilities

Replacement Rule RRC Sum (%)	Expected Life (yr)
40	47.8
45	54.7
50	64.3
55	74.2
60	85.0
65	99.2
70	113.8
100	150.6

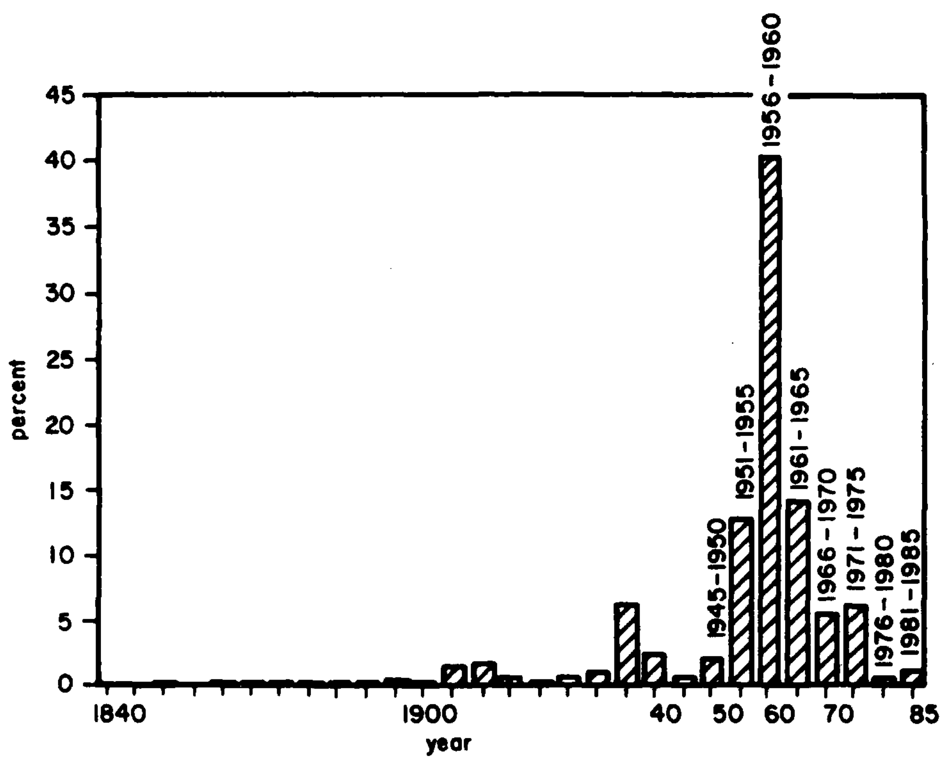

Figure 15. Family housing profile in TRADOC by year of construction.

In Figure 16, M&R and replacement costs of TRADOC family housing are presented by the unit of replacement cost equivalent. Since the replacement criterion of a low RRC sum requires early replacement of facilities, high facility cost due to replacement is shown in year 2005 by the 50 percent RRC replacement criterion. Using the 60 percent criterion defers replacement and reaches a peak around 2050. Facility cost fluctuates very much in the future because family housing construction was not spread well enough to reduce the cost fluctuation.

For the 60 percent RRC criterion, Figure 17 shows the facility cost requirement and Figure 18 shows the average age of family housing in TRADOC. A continuous increase in replacement cost and facility cost requirement is observed until the year 2010. After the temporary decline, both costs peak around 2050. However, M&R cost remains quite stable—around a 2 percent level of total replacement cost. High replacement costs are compensated by the reduction in M&R cost. This result implies that M&R cost and replacement cost requirements might be considered together.

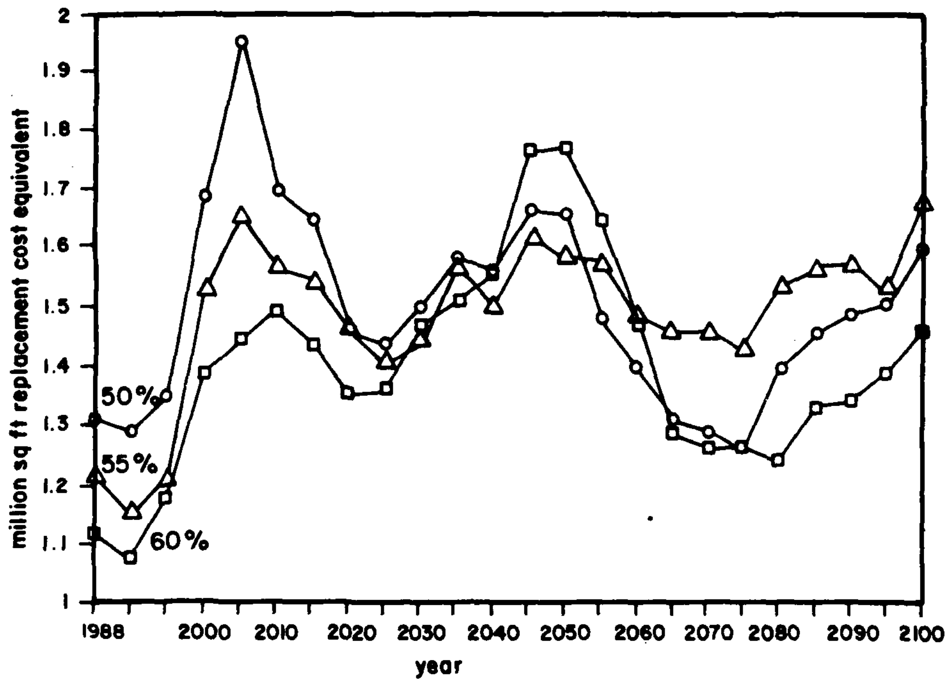

Figure 16. Total cost for TRADOC family housing.

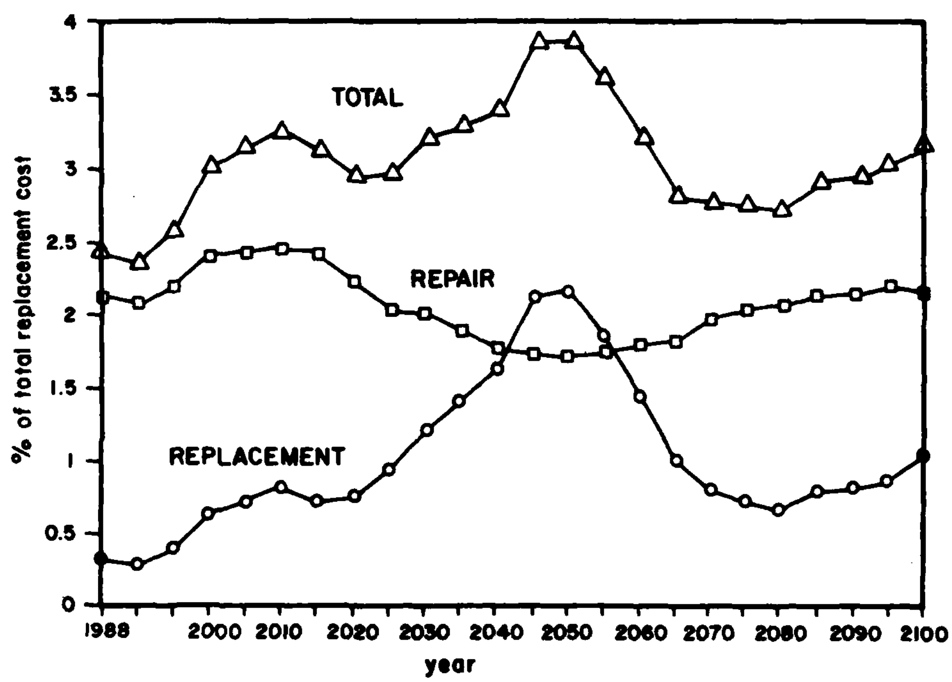

Figure 17. Replacement and M&R requirements for family housing in TRADOC (relative repair cost = 60 percent).

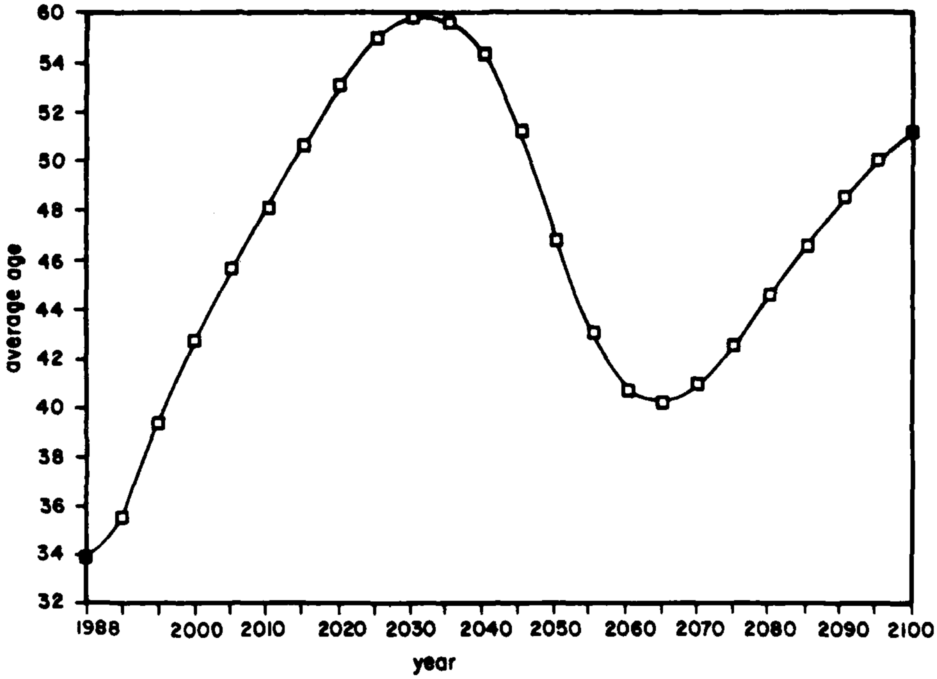

Figure 18. Average age of family housing in TRADOC (relative repair cost = 60 percent).

4 SUMMARY OF FINDINGS

Simulation Model Outcome

Operational research attempts to represent the real world in simple mathematical forms to help resolve complex problems. A similar approach was adopted for the facility management simulation models in this study. The results suggest interesting new outlooks for facility management.

A facility was considered as a set of replaceable and nonreplaceable components. Each replaceable component serves for a probabilistic life which is represented by a Weibull distribution. M&R costs of a facility are viewed as a result of replacements at the time of failure of replaceable components. Each component is assumed marginal in service quality during the fourth quarter of its life.

A facility is replaced if the relative repair cost sum of its marginal components in a certain year exceeds a given limit. Relative repair cost is a ratio that has replacement cost of a component as a numerator and market value of the facility as the denominator. The restored value, which considers depreciation of unreplaceable components, is used as a proxy of market value for the facility.

These concepts were applied to develop three simulation models to: (1) estimate M&R cost behavior by a facility's age, (2) examine facility replacement criteria, and (3) predict the future facility management cost. The family housing category was chosen for model experimentation.

In Army family housing, average M&R cost fluctuates by age of housing. A new repair cycle begins after heavy repair cost spending. This result implies that M&R cost by average age is very difficult to estimate from the average M&R cost by age. Consequently, adopting average age as an independent variable might be questioned when measuring the M&R cost requirement. A linear expression of M&R cost might be valid at best for managerial purposes during the age period 10 to 55 years.

Several different relative repair costs were adopted as facility replacement criteria and the resulting consequence of each criterion was measured by annual average facility management cost. Sixty percent of relative repair cost was shown to be a long-run optimal value as a facility replacement criterion.

The facility inventory profiles by construction year and spatial quantity in FORSCOM and TRADOC were used to predict facility management costs until the year 2100. Continuous cost increases were predicted for both replacement and M&R until the year 2010. After a temporary decline, facility management cost peaks around the year 2050 due to the continuous increase of replacement cost up to that year. M&R costs stay relatively stable at a 2 percent level of the replacement value for the coming 100 years by adopting the 60 percent replacement criterion.

Future Research

Although the modeling convention presented in this report is a first step in a quantitative approach to facility management, it is worthwhile to experiment with other categories of buildings. Preventive maintenance or minor repair might be considered as a first extension of this research without much difficulty. Adding other renewal alternatives (e.g., modernization or renovation of a facility) might be a potential extension of this research.

Developing facility replacement decision criteria would be very useful in rationalizing the replacement activity in the field. Further study might be necessary to search for a better proxy of market value or other valuation method of a facility to ensure a rigorous relative repair cost measure. Another good contribution in this area might be to develop an expert system to facilitate the field manager's renewal decision.

5 CONCLUSIONS AND RECOMMENDATIONS

Three cost simulation models have been developed and applied experimentally as part of a continuing effort to improve techniques for managing Army real property. The models consider a facility as an assembly of components, of which some are replaceable and others are nonreplaceable. The two major input variables are service life of an individual component and its replacement cost.

To assess the models' potential application to the Army, they were used to conduct experimental simulations using family housing as the facility type. The results have shown that this modeling approach offers a first step in understanding the behavior of facility costs and provides important hindsight for future facility management.

Simulation model I was successful in estimating M&R cost behavior by a facility's age. The study found that adopting average age as an independent variable when measuring M&R cost requirements is questionable; M&R cost as a linear expression of facility age might be valid at best only in the 10- to 55-year age range.

Simulation model II was used to examine facility replacement strategies using various criteria. Sixty percent of the RRC was found to be an optimal long-run value for a facility replacement criterion.

Future facility management costs were predicted using simulation model III. The facility inventory profiles by construction year and number in FORSCOM and TRADOC were used to predict the facility management cost until the year 2100. Continuous cost increases were predicted for both replacement and M&R until that year. After a temporary drop, facility management costs should peak around the year 2050 due to the continuous increase of replacement cost up to that year. Based on the experimental data, M&R costs stay relatively stable at a 2 percent level of the replacement value for 100 years into the future by adopting the 60 percent replacement criterion.

Based on these results, the following recommendations are made:

1. M&R cost should be considered along with the facility replacement policy--especially in budgeting--since the frequency of replacement affects M&R costs.

2. The facility inventory profile detailed in construction year and spatial quantity might be a relevant input to project the future M&R and replacement cost requirements since using average age of facilities as an independent variable appears inadequate to represent the fluctuating behavior of M&R cost.

3. Adopting average age of facilities as a managerial goal should be reviewed since average age is merely a result of a replacement policy, and not a *cause* of the policy. Moreover, due to the heavy construction during a certain period (e.g., 1950s and 1960s), family housing requires too high a replacement cost which might not be spread over a long enough interval to smooth the annual budget requirement if average age is applied as a replacement goal.

4. The relative repair cost measure might be a very useful criterion for facility replacement decision-making. RRC can indirectly reflect functionality and design as

well as physical condition of a facility by considering its market value as a dimension of effectiveness of the replacement decision.

5. To assess the models' applicability to Army facilities other than family housing, similar investigations should be performed, replacing this facility type with, for example, barracks, administrative buildings, and training facilities. If the models prove successful, they should be refined and suggested as alternatives to existing prediction methods.

REFERENCES

Bekker, P. C. F., "Influence of Durability on Material Consumption and Strategy of Building Industry," *Durability of Building Materials and Components*, Proceedings of the First International Conference. P. J. Sereda and G. G. Litvan (Eds.) (American Society for Testing and Materials [ASTM], August 1978).

Bon, Ranko, "Replacement Simulation Model (RSM): A Framework for Policy Decisions," unpublished paper (Department of Architecture, Massachusetts Institute of Technology, 1984).

Cannaday, Roger E., and Mark A. Sudman, "Estimation of Depreciation for Single-Family Appraisals," ORER Paper 11 (Office of Real Estate Research, University of Illinois, Urbana-Champaign, 1985).

Coskunoglu, Osman, and Alan W. Moore, *An Analysis of the Building Renewal Problem*, Technical Report P-87/11/ADB112755 (USA-CERL, 1987).

Frohnsdorff, Geoffrey, and L. W. Masters, "The Meaning of Durability Prediction," *Durability of Building Materials and Components*, ASTM STP 691, P. J. Sereda and G. G. Litvan (Eds.) (ASTM, 1978).

Hahn, G. H., and S. S. Shapiro, *Statistical Models in Engineering* (John Wiley and Sons, 1967).

Janicki, S., and St. Zaleski, "Bases for Maintenance, Repair and Modernization of Buildings," *Renewal, Rehabilitation and Maintenance*, Vol 16, CIB 23 (The National Swedish Institute for Building Research, 1983).

Jardine, A. K. S., *Maintenance, Replacement, and Reliability* (John Wiley and Sons, New York, 1973).

Mann, N. R., R. E. Schafer, and N. D. Singpuwalla, *Methods for Statistical Analysis of Reliability and Life Data* (John Wiley and Sons, 1974).

Martin, J. W., "Time Transformation Functions Commonly Used in Life Testing Analysis," *Durability of Building Materials and Components*, Proceedings of the First International Conference, G. Frohnsdorff and B. Horner (Eds.) (National Bureau of Standards, September 1981).

Mirham, G. A., *Simulation* (Academic Press, 1972).

Neathammer, R. D., *Life-Cycle Cost Data Base Design and Sample Data Development*, Interim Report P-120/ADA097222 (USA-CERL, 1981).

Pihlajavaara, S. E., "Background and Principles of Long-Term Performance of Building Materials," *Durability of Building Materials and Components*, ASTM STP 691, P. J. Sereda and G. G. Litvan (Eds.) (ASTM, 1978).

Replacement Cost - United States and Overseas (Facility Engineering Support Agency, 1986).

Residential/Light Commercial Cost Data - 1987, 6th annual ed. (R. S. Means Co., Inc).

APPPENDIX A:

SIMULATION I—M&R COST MODEL

Program

```
2  DIM COMP$(11),OPT(11),MOST(11),PESS(11),ETA1(11),SIGMA(11)
3  DIM COMPCOST(11),REPCOST(11),REPCOSTP(11)
5 SPN=200
6 SP5=SPN/5
8 DIM ANNCOST(SPN),AVGREP(SPN),XTWICE(SPN),SUMCOST(14),PSUM(14),PAVGREP(14)
9 DIM STNDEV(14),SUMVAR(14),SUMCOST%(14),RPMAPCT5(SP5)
10 REM     SIMULATION_MODEL: BUILDING COMPONENTS REPLACEMENT ONLY WITHOUT
11 REM                       REPLACING  THE WHOLE BUILDING
12 REM       (1) THIS SIMULATION MODEL IS DEVELOPED TO FIND OUT THE REPAIR
13 REM           COST REQUIREMENT WHEN A BUILDING IS ONLY REPAIRED WITHOUT
14 REM           REPLACING THE WHOLE BUILIDING.  THE RESULT WILL BE USED
15 REM           TO COMPARE IT WITH THE RESULT OF OTHER SIMULATION MODEL
16 REM           APPLYING A CERTAIN DECISION RULE TO REPLACE THE BUILDING.
20 REM       (2) THE LIFE LENGTH OF A BUILDING COMPONENT IS ASSUMED FOLLOWING
21 REM           WEIBULL DISTRIBUTION.
25 REM       (3) TO DETERMINE THE PARAMETERS IN WEIBULL DISTRIBUTION OF A
26 REM           COMPONENT, THE LIFE OF A COMPONENT IS ESTIMATED BY THREE WAYS,
27 REM           I.E., OPTIMISTIC, PESSIMISTIC AND MOST LIKELY LIFE LENGTH.
28 REM           (ASSUMPTION IN WEIBULL PARAMETER GENERATION: (a) a component
29 REM           never fails earlier than its pessimistic life length.
30 REM           (b) A probability of a component failure after its optimistic
31 REM           life is less than a given value; this value should be given
32 REM           as an input (TAIL_RIGHT) at the beginning. TAIL_RIGHT = 0.01
33 REM           is recommended.)
35 REM
40 REM     SUBROUTINE 1000: TO ESTIMATES THE VALUES OF sigma (scale
50 REM           parameter) and eta (shape parameter) in weibull distribution
55 REM
60 REM     SUBROUTINE 2000: to provide input data of component cost.
65 REM
200 GOSUB 1000
210 GOSUB 2000
220 RANDOMIZE TIMER
300 INPUT "# of BUILDINGS =";TURN
330 FOR ITURN=1 TO TURN
345 FOR RX=1 TO SPN : XTWICE(RX)=0  : NEXT RX
350 FOR C=1 TO 11
360 YRREP=0
390 REM -------- following function generates a life of component by weibull
391 REM          distribution.
395 PESSC=PESS(C) : SIGMAC=SIGMA(C) : ETA1C=ETA1(C)
396 RPCP=REPCOSTP(C)*(.9+.2*RND)
400 FAILTIME=PESSC+SIGMAC*(-LOG(RND))^(1/ETA1C)
410 YRFAIL=INT(FAILTIME)             : REM --- year of component failure
420 YRREP=YRREP+YRFAIL               : REM --- year of component failure
431 IF YRREP>SPN THEN 490
438 IF C=2 THEN XTWICE(YRREP)=1         : REM --- To eliminate major double
439 IF C=4 AND XTWICE(YRREP)=1 THEN 400  : REM     counting in costs est.
440 ANNCOST(YRREP)=ANNCOST(YRREP)+RPCP
450 GOTO 400
490 NEXT C
500 NEXT ITURN
600 FOR I=1 TO 14 : PSUM(I)=0 : NEXT I
610 FOR FY=1 TO SPN
620 AVGREP(FY)=ANNCOST(FY)/TURN
625 CY=ANNCOST(FY)/100
630 SUMCOST(1)=SUMCOST(1)+CY
635 PSUM(1)=PSUM(1)+AVGREP(FY)
640 FOR LATE=5 TO 14
645 YLATE=LATE*10
```

```
650 IF FY>YLATE THEN SUMCOST(LATE)=SUMCOST(LATE)+CY
655 NEXT LATE
660 FOR LT=5 TO 14
665 YPL=LT*10
670 IF FY>YPL THEN PSUM(LT)=PSUM(LT)+AVGREP(FY)
680 NEXT LT
690 NEXT FY
700 PAVGREP(1)=PSUM(1)/SPN
701 FOR L=5 TO 14
703 YRREM=SPN-L*10
705 PAVGREP(L)=PSUM(L)/YRREM
707 NEXT L
710 FOR I=1 TO 14 : SUMVAR(I)=0 : NEXT I
725 FOR LL=1 TO 14
726 IF LL>1 AND LL<5 THEN 735
727 YB=10*LL+1   : IF LL=1 THEN YB=1
728 FOR Y=YB TO SPN
730 SUMVAR(LL)=SUMVAR(LL)+(AVGREP(Y)-PAVGREP(LL))^2
732 NEXT Y
735 NEXT LL
740 FOR CR=1 TO 14
745 IF CR>1 AND CR<5 THEN 755
747 SS=SPN-CR*10
748 IF CR=1 THEN SS=SPN
750 STNDEV(CR)=(SUMVAR(CR)/SS)^.5
755 NEXT CR
760 PRINT " YEAR          ANNUAL_REPAIR_COST(% OF CONSTRUCTION COST)"
770 PRINT " ----          -------------------------------------------"
780 FOR YR=1 TO SPN
790 PRINT USING"  ###";YR;
800 PRINT USING"                         ##.##";AVGREP(YR)
810 NEXT YR
820 FOR I=1 TO 14 : SUMCOST%(I)=SUMCOST(I) : NEXT I
840 PRINT "            SUMMARY STATISTICS"
850 PRINT "            ------------------"
855 FOR RT=1 TO 14
856 IF RT>1 AND RT<5 THEN 950
857 PERIOD=SPN-RT*10
858 IF RT=1 THEN PERIOD=SPN
859 PRINT "RESULTS FOR THE REMAINING";PERIOD;"YEARS"
860 PRINT "ANNUAL AVG. REPAIR COST (% OF CONSTRUCTION) =";
870 PRINT USING" ##.##";PAVGREP(RT)
880 PRINT "STANDARD DEV. OF ANN. AVG. REP. COST(% CON) =";
890 PRINT USING" ##.##";STNDEV(RT)
900 PRINT "TOTAL REPAIR COST YEARS(BLDG. EQIV) =";SUMCOST%(RT)
940 PRINT "-----------------------------------------"
950 NEXT RT
960 GOSUB 3000
990 END
1000 REM -------- "ESTIMATION OF WEIBULL DISTRIBUTION"
1001 REM
1010 INPUT "tail(right) = ";RTAIL
1020 X=LOG(RTAIL)
1030 XX=LOG(-X)
1040 PRINT "component            pessimistic   likely   optimistic   eta   sig
1050 FOR I=1 TO 11 : READ COMP$(I) : NEXT I
1060 FOR I=1 TO 11 : READ OPT(I) : NEXT I
1070 FOR I=1 TO 11 : READ MOST(I) : NEXT I
1080 FOR I=1 TO 11 : READ PESS(I) : NEXT I
1090 FOR CP=1 TO 11
```

```
1100 MODE=MOST(CP)-PESS(CP)
1110 TOPT=OPT(CP)-PESS(CP)
1120 RATIO=TOPT/MODE
1130 FOR TA=0 TO 100
1140 ETA=2+.1*TA
1150 TEST=ETA*LOG(RATIO)-LOG(ETA)+LOG(ETA-1)-XX
1170 IF TEST>0 THEN 1190
1180 NEXT TA
1190 RETA=1/ETA
1200 DIV=((ETA-1)/ETA)^RETA
1210 SGMA=MODE/DIV
1220 SIGMA(CP)=INT(SGMA)
1225 ETA1(CP)=ETA
1230 PRINT COMP$(CP);"   ";
1240 PRINT USING"     ###     ";PESS(CP);MOST(CP);OPT(CP);
1250 PRINT USING"    #.#    ";ETA1(CP);
1260 PRINT USING "  ### ";SIGMA(CP)
1270 NEXT CP
1280 DATA "roofing          ","ext. cladding   ","ext. door/window"
1290 DATA "ext. finishes    ","int. partitions ","int. doors      "
1300 DATA "int. finishes    ","mech.-moving    ","mech.-static    "
1310 DATA "electrical       ","special         "
1320 DATA 35,70,100,25,150,125,25,25,80,75,50
1330 DATA 25,50,60,20,100,75,15,15,50,50,30
1340 DATA 10,30,30,15,75,40,7,10,30,25,10
1350 RETURN
2000 REM "generation of cost data for the replacement of a component"
2005 REM  Most of the repair works requires more cost than construction:
2006 REM     Repair jobs might acompany with some side effects, i.e., plumbing
2007 REM     job frequently damages wall or floor, and require extra labor to
2008 REM     remove the failed components.
2020 FOR I=1 TO 11 : READ COMPCOST(I) : NEXT I
2030 FOR I=1 TO 11 : REPCOST(I)=COMPCOST(I) : NEXT I
2035 REPCOST(1)=1.1*COMPCOST(1)
2040 REPCOST(2)=1.1*COMPCOST(2)+COMPCOST(4)+.05*COMPCOST(10)
2050 REPCOST(3)=1.05*COMPCOST(3)+.05*COMPCOST(4)+.05*COMPCOST(7)
2060 REPCOST(4)=1.5*COMPCOST(4)+.05*COMPCOST(10)
2070 REPCOST(5)=COMPCOST(5)+.15*COMPCOST(10)+.35*COMPCOST(7)
2080 REPCOST(9)=1.3*COMPCOST(9)+.15*COMPCOST(5)+.03*COMPCOST(7)
2090 REPCOST(10)=COMPCOST(10)+.05*COMPCOST(5)+.01*COMPCOST(7)
2100 REPCOST(11)=COMPCOST(11)+.05*COMPCOST(5)+.02*COMPCOST(9)+.02*COMPCOST(10)
2105 REPCOST(11)=REPCOST(11)+.01*COMPCOST(7)
2110 TREPCOST=0
2114 COSTFDN=3.96 : REM --- cost of foundation ($/sq.ft)
2115 COSTFRM=5.45 : REM --- cost of framing ($/sq.ft)
2116 OVERCOST=COSTFDN+COSTFRM
2120 TCONCOST=0
2130 FOR I=1 TO 11
2140 TREPCOST=TREPCOST+REPCOST(I)
2150 NEXT I
2160 FOR I=1 TO 11
2170 TCONCOST=TCONCOST+COMPCOST(I)
2180 NEXT I
2190 REPCON=TREPCOST/TCONCOST
2200 PRINT "average_excess_cost_of_repair/construction_cost = ";REPCON
2205 TCONCOST=TCONCOST+OVERCOST
2210 FOR I=1 TO 11 : REPCOSTP(I)=REPCOST(I)*100/TCONCOST : NEXT I
2220 FOR I=1 TO 11
2230 PRINT "repair cost (";COMP$(I);") = ";
2235 PRINT USING" ##.#";REPCOSTP(I);
```

```
2236 PRINT "% of net_replacement_cost"
2240 NEXT I
2250 DATA 1.25,2.66,3.96,0.9,4.82,1.28,4.4,1.9,1.9,.85,1.47
2260 RETURN
3000 REM --------- "RPMA COST (%) EVERY FIVE YEARS PERIOD"
3010 PRINT "____________________________________________________________"
3020 PRINT
3030 PRINT "          TABLE: RPMA COST (%) WITHOUT NEW CONSTRUCTION"
3040 PRINT "          ----------------------------------------------"
3050 PRINT " YEARS            AVG. ANNUAL       ACCUMULATE      LONGRUN TOTAL"
3060 PRINT "FROM - TO         RPMA COST(%)      RPMA COST(%)    AVERAGE COST(%)"
3070 PRINT "---------         ------------      ------------    ---------------"
3075 OPTLRCST=100
3080 FOR I=1 TO SP5
3090 BY=5*I-4      : EY=5*I
3100 FOR J=BY TO EY
3110 RPMAPCT5(I)=RPMAPCT5(I)+AVGREP(J)
3120 NEXT J
3130 ACRPMA=ACRPMA+RPMAPCT5(I)
3140 ANNRPMA=RPMAPCT5(I)/5
3142 LRAVCOST=(100+ACRPMA)/EY
3144 IF LRAVCOST>OPTLRCST THEN 3150
3145 OPTLRCST=LRAVCOST
3146 OPTLRYR=EY
3150 PRINT USING"###";BY;
3160 PRINT " - ";
3170 PRINT USING"###     ";EY;
3180 PRINT USING"     ###.##      ";ANNRPMA,ACRPMA,LRAVCOST
3190 NEXT I
3200 PRINT "-------------------------------------------------------------------"
3210 PRINT
3220 PRINT "OPTIMAL LONG RUN TOATAL AVERAGE COST =";
3230 PRINT USING"##.###";OPTLRCST;
3240 PRINT " IN YEAR";OPTLRYR
```

Output

```
tail(right) = ? .01
component             pessimistic   likely   optimistic   eta   sigma
roofing                    10          25         35        3.7     16
ext. cladding              30          50         70        2.9     23
ext. door/window           30          60        100        2.5     36
ext. finishes              15          20         25        2.9      5
int. fin.(long)            75         100        150        2.1     34
int. doors                 40          75        125        2.4     43
int. fin.(short)            7          15         25        2.6      9
mech.-moving               10          15         25        2.1      6
mech.-static               30          50         80        2.3     25
electrical                 25          50         75        2.9     28
special                    10          30         50        2.9     23
average_excess_cost_of_repair/construction_cost =  1.23657
repair cost (roofing         ) =   4.0% of net_replacement_cost
repair cost (ext. cladding   ) =  11.1% of net_replacement_cost
repair cost (ext. door/window) =  12.7% of net_replacement_cost
repair cost (ext. finishes   ) =   4.0% of net_replacement_cost
repair cost (int. partitions ) =  18.6% of net_replacement_cost
repair cost (int. doors      ) =   3.7% of net_replacement_cost
repair cost (int. finishes   ) =  12.6% of net_replacement_cost
repair cost (mech.-moving    ) =   5.5% of net_replacement_cost
repair cost (mech.-static    ) =   9.6% of net_replacement_cost
repair cost (electrical      ) =   3.3% of net_replacement_cost
repair cost (special         ) =   5.2% of net_replacement_cost
# of BUILDINGS =? 2000
```

YEAR	ANNUAL_REPAIR_COST(% OF CONSTRUCTION COST)
1	0.00
2	0.00
3	0.00
4	0.00
5	0.00
6	0.00
7	0.02
8	0.18
9	0.57
10	0.88
11	1.35
12	1.66
13	2.44
14	2.46
15	2.24
16	2.11
17	2.24
18	2.27
19	2.19
20	1.80
21	1.38
22	1.43
23	1.36
24	1.47
25	1.67
26	2.12
27	2.07
28	2.02
29	2.32
30	2.01
31	1.92
32	1.82
33	1.72
34	1.64
35	1.81
36	2.12
37	2.44
38	2.35
39	2.59
40	2.74
41	2.82
42	2.76
43	2.80
44	2.97
45	2.84
46	2.95
47	2.99
48	2.83
49	2.80
50	2.95
51	2.96
52	3.08
53	3.08
54	3.27
55	3.17
56	3.15
57	3.21
58	3.43
59	3.15
60	2.93
61	2.80
62	2.50
63	2.32
64	2.25
65	2.33

66	2.09
67	2.23
68	1.93
69	2.17
70	2.19
71	2.26
72	2.35
73	2.49
74	2.50
75	2.64
76	2.46
77	2.54
78	2.56
79	2.47
80	2.29
81	2.30
82	2.27
83	2.29
84	2.31
85	2.41
86	2.64
87	2.57
88	2.66
89	2.62
90	2.96
91	2.96
92	3.13
93	3.18
94	3.20
95	3.32
96	3.26
97	3.32
98	3.18
99	3.13
100	3.31
101	3.26
102	2.96
103	3.05
104	2.92
105	3.15
106	2.84
107	2.96
108	3.04
109	3.04
110	3.15
111	2.88
112	3.11
113	2.96
114	3.29
115	3.03
116	2.59
117	2.95
118	2.89
119	2.75
120	2.55
121	2.45
122	2.54
123	2.38
124	2.38
125	2.50
126	2.39
127	2.43
128	2.20
129	2.55
130	2.60
131	2.70
132	2.73

133	2.61
134	2.85
135	2.56
136	2.64
137	2.56
138	2.66
139	2.54
140	2.43
141	2.54
142	2.28
143	2.50
144	2.46
145	2.88
146	2.60
147	2.41
148	2.74
149	2.77
150	2.76
151	2.75
152	2.86
153	2.63
154	2.80
155	2.60
156	2.77
157	2.59
158	2.45
159	2.84
160	2.35
161	2.57
162	2.46
163	2.39
164	2.42
165	2.57
166	2.71
167	2.50
168	2.46
169	2.41
170	2.55
171	2.51
172	2.47
173	2.62
174	2.51
175	2.59
176	2.41
177	2.39
178	2.55
179	2.46
180	2.59
181	2.52
182	2.55
183	2.66
184	2.59
185	2.74
186	2.75
187	2.63
188	2.91
189	2.53
190	2.86
191	2.88
192	2.99
193	2.88
194	2.74
195	3.01
196	2.87
197	2.88
198	2.83
199	2.94
200	2.81

SUMMARY STATISTICS

```
RESULTS FOR THE REMAINING 200 YEARS
ANNUAL AVG. REPAIR COST (% OF CONSTRUCTION) =  2.47
STANDARD DEV. OF ANN. AVG. REP. COST(% CON) =  0.66
TOTAL REPAIR COST YEARS(BLDG. EQIV) = 9886
-------------------------------------------
RESULTS FOR THE REMAINING 150 YEARS
ANNUAL AVG. REPAIR COST (% OF CONSTRUCTION) =  2.69
STANDARD DEV. OF ANN. AVG. REP. COST(% CON) =  0.30
TOTAL REPAIR COST YEARS(BLDG. EQIV) = 8084
-------------------------------------------
RESULTS FOR THE REMAINING 140 YEARS
ANNUAL AVG. REPAIR COST (% OF CONSTRUCTION) =  2.66
STANDARD DEV. OF ANN. AVG. REP. COST(% CON) =  0.29
TOTAL REPAIR COST YEARS(BLDG. EQIV) = 7455
-------------------------------------------
RESULTS FOR THE REMAINING 130 YEARS
ANNUAL AVG. REPAIR COST (% OF CONSTRUCTION) =  2.69
STANDARD DEV. OF ANN. AVG. REP. COST(% CON) =  0.27
TOTAL REPAIR COST YEARS(BLDG. EQIV) = 6999
-------------------------------------------
RESULTS FOR THE REMAINING 120 YEARS
ANNUAL AVG. REPAIR COST (% OF CONSTRUCTION) =  2.71
STANDARD DEV. OF ANN. AVG. REP. COST(% CON) =  0.27
TOTAL REPAIR COST YEARS(BLDG. EQIV) = 6507
-------------------------------------------
RESULTS FOR THE REMAINING 110 YEARS
ANNUAL AVG. REPAIR COST (% OF CONSTRUCTION) =  2.73
STANDARD DEV. OF ANN. AVG. REP. COST(% CON) =  0.27
TOTAL REPAIR COST YEARS(BLDG. EQIV) = 6007
-------------------------------------------
RESULTS FOR THE REMAINING 100 YEARS
ANNUAL AVG. REPAIR COST (% OF CONSTRUCTION) =  2.68
STANDARD DEV. OF ANN. AVG. REP. COST(% CON) =  0.23
TOTAL REPAIR COST YEARS(BLDG. EQIV) = 5367
-------------------------------------------
RESULTS FOR THE REMAINING 90 YEARS
ANNUAL AVG. REPAIR COST (% OF CONSTRUCTION) =  2.64
STANDARD DEV. OF ANN. AVG. REP. COST(% CON) =  0.20
TOTAL REPAIR COST YEARS(BLDG. EQIV) = 4760
-------------------------------------------
RESULTS FOR THE REMAINING 80 YEARS
ANNUAL AVG. REPAIR COST (% OF CONSTRUCTION) =  2.61
STANDARD DEV. OF ANN. AVG. REP. COST(% CON) =  0.18
TOTAL REPAIR COST YEARS(BLDG. EQIV) = 4180
-------------------------------------------
RESULTS FOR THE REMAINING 70 YEARS
ANNUAL AVG. REPAIR COST (% OF CONSTRUCTION) =  2.64
STANDARD DEV. OF ANN. AVG. REP. COST(% CON) =  0.17
TOTAL REPAIR COST YEARS(BLDG. EQIV) = 3691
-------------------------------------------
RESULTS FOR THE REMAINING 60 YEARS
ANNUAL AVG. REPAIR COST (% OF CONSTRUCTION) =  2.64
STANDARD DEV. OF ANN. AVG. REP. COST(% CON) =  0.18
TOTAL REPAIR COST YEARS(BLDG. EQIV) = 3166
-------------------------------------------
```

TABLE: RPMA COST (%) WITHOUT NEW CONSTRUCTION

YEARS FROM - TO	AVG. ANNUAL RPMA COST(%)	ACCUMULATE RPMA COST(%)	LONGRUN TOTAL AVERAGE COST(%)
1 - 5	0.00	0.00	20.00
6 - 10	0.33	1.65	10.17
11 - 15	2.03	11.81	7.45
16 - 20	2.12	22.42	6.12
21 - 25	1.46	29.72	5.19
26 - 30	2.11	40.25	4.67
31 - 35	1.78	49.17	4.26
36 - 40	2.45	61.41	4.04
41 - 45	2.84	75.60	3.90
46 - 50	2.90	90.11	3.80
51 - 55	3.11	105.67	3.74
56 - 60	3.17	121.55	3.69
61 - 65	2.44	133.75	3.60
66 - 70	2.13	144.38	3.49
71 - 75	2.45	156.62	3.42
76 - 80	2.47	168.95	3.36
81 - 85	2.31	180.52	3.30
86 - 90	2.69	193.98	3.27
91 - 95	3.16	209.78	3.26
96 - 100	3.24	225.97	3.26
101 - 105	3.07	241.31	3.25
106 - 110	3.01	256.33	3.24
111 - 115	3.05	271.60	3.23
116 - 120	2.75	285.33	3.21
121 - 125	2.45	297.58	3.18
126 - 130	2.43	309.74	3.15
131 - 135	2.69	323.19	3.13
136 - 140	2.57	336.02	3.11
141 - 145	2.53	348.69	3.09
146 - 150	2.66	361.97	3.08
151 - 155	2.73	375.61	3.07
156 - 160	2.60	388.61	3.05
161 - 165	2.48	401.03	3.04
166 - 170	2.53	413.65	3.02
171 - 175	2.54	426.36	3.01
176 - 180	2.48	438.76	2.99
181 - 185	2.61	451.82	2.98
186 - 190	2.73	465.49	2.98
191 - 195	2.90	479.98	2.97
196 - 200	2.87	494.31	2.97

OPTIMAL LONG RUN TOATAL AVERAGE COST = 2.972 IN YEAR 200

APPENDIX B:

SIMULATION II—REPLACEMENT DECISION MODEL

Program

```
10  DIM COMP$(11),OPT(11),MOST(11),PESS(11),ETA1(11),SIGMA(11),COMPCOST(11)
20  DIM REPCOST(11),REPCOSTP(11),SUMCOST(6),RSUMCOST(6),SUMYEAR(6)
30  SPN=150      :REM --- TEST PERIOD IN YEARS
40  SP1=SPN+1 : SP5=SPN/5
50  DIM PYRCOST(SP1),REPFQ(SP1),RPMA(SPN),RRPMA(SPN),XTWICE(SP1),XRTWICE(SP1)
60  DIM ACTVALUE(SP1),LRAVCOST(8,6),RLRAVCOST(8,6)
70  REM      SIMULATION MODEL: REPAIR COST vs REPLACEMENT COST
80  REM        (1) LIFE OF A BUILDING IS ESTIMATED BY SIMULATING THE LIFE OF EACH
90  REM            BUILDING COMPONENT.
100 REM        (2) THE LIFE LENGTH OF A BUILDING COMPONENT IS ASSUMED FOLLOWING
110 REM            WEIBULL DISTRIBUTION.
120 REM        (3) TO DETERMINE THE PARAMETERS IN WEIBULL DISTRIBUTION OF A
130 REM            COMPONENT, THE LIFE OF A COMPONENT IS ESTIMATED BY THREE WAYS,
140 REM            I.E., OPTIMISTIC, PESSIMISTIC AND MOST LIKELY LIFE LENGTH.
150 REM            (ASSUMPTION IN WEIBULL PARAMETER GENERATION: (a) a component
160 REM            never fails earlier than its pessimistic life length.
170 REM            (b) A probability of a component failure after its optimistic
180 REM            life is less than a given value; this value should be given
190 REM            as an input (TAIL_RIGHT) at the beginning. TAIL_RIGHT = 0.01
200 REM            is recommended.)
210 REM
220 REM      SUBROUTINE 3000: TO ESTIMATES THE VALUES OF sigma (scale
230 REM            parameter) and eta (shape parameter) in weibull distribution
240 REM
250 REM      SUBROUTINE 4000: To provide input data of component cost.
260 REM
265 REM      SUBROUTINE 4500: To generate the depreciation rate of a facility.
266 REM
270 REM      ASSUMPTION: MARGINAL CONDITION OF A COMPONENT
280 REM            IF REMAINING LIFE OF A COMPONENT IS LESS THAN 25 PER CENT OF
290 REM            ITS NATURAL LIFE, THE CONDITION OF THE COMPONENT IS ASSUMED
300 REM            MARGINAL.
310 REM
320 REM      DEFINITION: RELATIVE REPAIR COST
330 REM            RELATIVE REPAIR COST=REPAIR COST/(1-RATE OF DEPRECIATION)
340 REM            I.E., ADJUSTED VALUE OF REPAIR COST BY CONSIDERING EXCHANGE
350 REM            VALUE OF A FACILITY.
360 REM
365 REM      DECISION RULE OF BUILDING REPLACEMENT:
370 REM            IF SEVERAL COMPONENTS ARE IN MARGINAL CONDITION AND (RELATIVE)
380 REM            REPAIR COSTS FOR THESE COMPONENTS EXCEEDS SOME LIMIT IN A
390 REM            CERTAIN YEAR, THEN THE WHOLE BUILDING IS REPLACED.  OTHERWISE,
400 REM            EACH COMPONENT IS USED UNTIL IT FAILS.
410 REM
420 REM      NOTE: IN THIS PROGRAM YOU MAY USE ABSOLUTE REPAIR COST OR RELATIVE
430 REM            REPAIR COST AS A REPLACEMENT DECISION RULE BY DECLARING AS AN
440 REM            INPUT TO RUN THE PROGRAM.
450 REM
460 REM      DEFINITION: NET_REPLACEMENT_COST
470 REM            NET REPLACEMENT COST of a building is the cost of duplication
480 REM            EXCLUDING costs of site work, design and contract overhead.
490 GOSUB 3000
500 GOSUB 4000
510 GOSUB 4500
520 RANDOMIZE TIMER
530 PRINT "Choose absolute(A) or relative(R) repair cost as a replacement"
540 PRINT "decision rule. Type A or R."
550 INPUT "Replacement decision rule?",DRULE$
560 IF DRULE$="R" OR DRULE$="r" THEN 580
570 FOR I=1 TO SP1 : ACTVALUE(I)=1 : NEXT I
```

```
580 INPUT "# of simulation =";TURN
590 PRINT "DEFINITION ---- NET_REPLACEMENT_COST: Duplication cost excluding
600 PRINT "                 cost of site work, design and contract overhead."
610 PRINT
620 FOR TEST=1 TO 8
630 REP%=35+TEST*5
640 IF TEST=8 THEN REP%=100
650 FOR I=1 TO SP1 : REPFQ(I)=0 : NEXT I
660 IF REP%=<66 THEN EARLY=22 ELSE EARLY=30
665 FOR SIM=1 TO 6
670 SUMCOST(SIM)=0 : RSUMCOST(SIM)=0 : SUMYEAR(SIM)=0
675 NEXT SIM
680 FOR ITURN=1 TO TURN
690 FOR YR=1 TO SPN
700 PYRCOST(YR)=0
710 RPMA(YR)=0
715 RRPMA(YR)=0
720 XTWICE(YR)=0
730 XRTWICE(YR)=0
740 NEXT YR
750 FOR C=1 TO 11
760 REM -------- following function generates a life of component by weibull
770 REM          distribution.
775 YRREP=0
780 PESSC=PESS(C) : SIGMAC=SIGMA(C) : ETA1C=ETA1(C)
790 RPCP=REPCOSTP(C)*(.9+.2*RND)
793 RRD=RND
795 OVFL=10^(-38)
796 IF RRD<OVFL THEN RRD=OVFL
800 FAILTIM=PESSC+SIGMAC*(-LOG(RRD))^(1/ETA1C)
810 YRFAIL=INT(FAILTIM)
820 YRREP=YRREP+YRFAIL               : REM --- year of component failure
830 BYRMAR=YRREP+1-INT(YRFAIL*.25)   : REM --- biginning year of marginal cond.
840 IF BYRMAR>SPN THEN 990
850 IF YRREP>SPN THEN 900
860 REM -------- Repair cost of a component
870 IF C=2 THEN XRTWICE(YRREP)=1 : REM --- To eliminate major double counting
880 IF C=4 AND XRTWICE(YRREP)=1 THEN 930
890 RPMA(YRREP)=RPMA(YRREP)+RPCP
895 RRPMA(YRREP)=RRPMA(YRREP)+RPCP/ACTVALUE(YRREP)
900 IF YRREP>SPN THEN YRREP=SP1
910 REM -------- Following function generates potential repair costs of
920 REM          components which are in marginal condition.
930 FOR MAR=BYRMAR TO YRREP
940 IF C=2 THEN XTWICE(MAR)=1               : REM --- To eliminate major double
950 IF C=4 AND XTWICE(MAR)=1 THEN 970       : REM     counting in costs est.
960 PYRCOST(MAR)=PYRCOST(MAR)+RPCP/ACTVALUE(MAR)
970 NEXT MAR
980 GOTO 793
990 NEXT C
1000 REM -------- Following routine simulates a time of replacement.
1010 REPYEAR=SP1
1020 FOR Y=EARLY TO SP1
1060 IF PYRCOST(Y)<REP% THEN 1100
1070 PREPY=Y
1080 IF PREPY=SP1 THEN 1190
1090 GOTO 1120
1100 NEXT Y
1110 GOTO 1190
1115 PEAKSAVE=PYRCOST(PREPY)
```

```
1120 YBG=PREPY+1
1130 REM --- To postpone the replacement as long as possible under the rule.
1140 FOR K=YBG TO SP1
1150 IF PYRCOST(K)>=PEAKSAVE THEN 1175
1160 REPYEAR=K-1
1170 GOTO 1190
1175 PEAKSAVE=PYRCOST(K)
1180 NEXT K
1190 REPFQ(REPYEAR)=REPFQ(REPYEAR)+1     : REM --- annual new construction
1200 ENDRP=REPYEAR-1
1210 TOTCOST=0 : RTOTCOST=0
1220 REM -------- Annual cost of repair estimation
1222 FOR SIMUL=1 TO 6
1223 SPAN=90+10*SIMUL
1224 STARP=SPAN-9 : IF SIMUL=1 THEN STARP=1
1225 STRP=ENDRP
1227 IF SPAN=<ENDRP THEN STRP=SPAN
1228 IF STARP>STRP THEN 1280
1230 FOR RYR=STARP TO STRP
1250 TOTCOST=TOTCOST+RPMA(RYR)
1260 RTOTCOST=RTOTCOST+RRPMA(RYR)
1270 NEXT RYR
1280 SUMCOST(SIMUL)=SUMCOST(SIMUL)+TOTCOST
1290 RSUMCOST(SIMUL)=RSUMCOST(SIMUL)+RTOTCOST
1300 SUMYEAR(SIMUL)=SUMYEAR(SIMUL)+STRP
1305 NEXT SIMUL
1310 NEXT ITURN
1340 GOSUB 5000
1350 NEXT TEST
1360 GOSUB 6000
1400 END
3000 REM -------- "ESTIMATION OF WEIBULL DISTRIBUTION"
3010 REM
3020 INPUT "tail(right) = ";RTAIL
3030 X=LOG(RTAIL)
3040 XX=LOG(-X)
3050 PRINT "component             pessimistic   likely    optimistic    eta    sig
3060 FOR I=1 TO 11 : READ COMP$(I) : NEXT I
3070 FOR I=1 TO 11 : READ OPT(I) : NEXT I
3080 FOR I=1 TO 11 : READ MOST(I) : NEXT I
3090 FOR I=1 TO 11 : READ PESS(I) : NEXT I
3100 FOR CP=1 TO 11
3110 MODE=MOST(CP)-PESS(CP)
3120 TOPT=OPT(CP)-PESS(CP)
3130 RATIO=TOPT/MODE
3140 FOR TA=0 TO 100
3150 ETA=2+.1*TA
3160 TEST=ETA*LOG(RATIO)-LOG(ETA)+LOG(ETA-1)-XX
3170 IF TEST>0 THEN 3190
3180 NEXT TA
3190 RETA=1/ETA
3200 DIV=((ETA-1)/ETA)^RETA
3210 SGMA=MODE/DIV
3220 SIGMA(CP)=INT(SGMA)
3230 ETA1(CP)=ETA
3240 PRINT COMP$(CP);"    ";
3250 PRINT USING"     ###     ";PESS(CP);MOST(CP);OPT(CP);
3260 PRINT USING"    #.#    ";ETA1(CP);
3270 PRINT USING "  ###  ";SIGMA(CP)
3280 NEXT CP
```

```
3290 DATA "roofing          ","ext. cladding   ","ext. door/window"
3300 DATA "ext. finishes    ","int. partitions ","int. doors      "
3310 DATA "int. finishes    ","mech.-moving    ","mech.-static    "
3320 DATA "electrical       ","special         "
3330 DATA 35,70,100,25,150,125,25,25,80,75,50
3340 DATA 25,50,60,20,100,75,15,15,50,50,30
3350 DATA 10,30,30,15,75,40,7,10,30,25,10
3360 RETURN
4000 REM "generation of cost data for the replacement of a component"
4010 REM  Most of the repair works requires more cost than construction:
4020 REM      Repair jobs might acompany with some side effects, i.e., plumbing
4030 REM      job frequently damages wall or floor, and require extra labor
4040 REM      to remove the failed components.
4050 FOR I=1 TO 11 : READ COMPCOST(I) : NEXT I
4060 FOR I=1 TO 11 : REPCOST(I)=COMPCOST(I) : NEXT I
4070 REPCOST(1)=1.1*COMPCOST(1)
4080 REPCOST(2)=1.1*COMPCOST(2)+COMPCOST(4)+.05*COMPCOST(10)
4090 REPCOST(3)=1.05*COMPCOST(3)+.05*COMPCOST(4)+.05*COMPCOST(7)
4100 REPCOST(4)=1.5*COMPCOST(4)+.05*COMPCOST(10)
4110 REPCOST(5)=COMPCOST(5)+.15*COMPCOST(10)+.35*COMPCOST(7)
4120 REPCOST(9)=1.3*COMPCOST(9)+.15*COMPCOST(5)+.03*COMPCOST(7)
4130 REPCOST(10)=COMPCOST(10)+.05*COMPCOST(5)+.01*COMPCOST(7)
4140 REPCOST(11)=COMPCOST(11)+.05*COMPCOST(5)+.02*COMPCOST(9)+.02*COMPCOST(10)
4150 REPCOST(11)=REPCOST(11)+.01*COMPCOST(7)
4160 TREPCOST=0
4170 COSTFDN=3.96 : REM --- cost of foundation ($/sq.ft)
4180 COSTFRM=5.45 : REM --- cost of framing ($/sq.ft)
4190 OVERCOST=COSTFDN+COSTFRM
4200 TCONCOST=0
4210 FOR I=1 TO 11
4220 TREPCOST=TREPCOST+REPCOST(I)
4230 NEXT I
4240 FOR I=1 TO 11
4250 TCONCOST=TCONCOST+COMPCOST(I)
4260 NEXT I
4270 REPCON=TREPCOST/TCONCOST
4280 PRINT "average_excess_cost_of_repair/construction_cost = ";REPCON
4290 TCONCOST=TCONCOST+OVERCOST
4300 FOR I=1 TO 11 : REPCOSTP(I)=REPCOST(I)*100/TCONCOST : NEXT I
4310 FOR I=1 TO 11
4320 PRINT "repair cost (";COMP$(I);") = ";
4330 PRINT USING" ##.#";REPCOSTP(I);
4340 PRINT "% of net_replacement_cost"
4350 NEXT I
4360 DATA 1.25,2.66,3.96,0.9,4.82,1.28,4.4,1.9,1.9,.85,1.47
4370 RETURN
4500 REM --- THIS SUBROUTINE GENERATES THE RELATIVE WORTH OF AN OLD FACILITY TO
4510 REM     THE NEW ONE.  LINEAR DEPRECIATION IS ASSUMED.
4520 ANNDEP=OVERCOST/(TCONCOST*75)
4530 FOR Y=1 TO 75
4540 ACTVALUE(Y)=1-Y*ANNDEP
4550 NEXT Y
4555 FOR Y=76 TO SP1 : ACTVALUE(Y)=ACTVALUE(75) : NEXT Y
4560 RETURN
5000 REM --------- NEW CONSTRUCTION (%) EVERY FIVE YEARS PERIOD"
5010 PRINT "________________________________________________________________"
5020 PRINT
5025 PRINT "         SUMMARY: (RELATIVE) REPAIR COST <";REP%;"%"
5026 PRINT "         ---------------------------------------"
5030 SUMAGE=0
```

```
5032 FOR Y=1 TO SP1
5035 SUMAGE=SUMAGE+Y*REPFQ(Y)
5040 NEXT Y
5042 AVGAGE=SUMAGE/TURN
5045 PRINT "          AVERAGE LIFE OF BUILDINGS =";
5047 PRINT USING"###.#";AVGAGE
5050 FOR SIMUL=1 TO 6
5060 SPAN=90+SIMUL*10
5070 PRINT "MAXIMUM LIFE ASSUMED";SPAN;"YEARS"
5120 LRAVCOST(TEST,SIMUL)=(SUMCOST(SIMUL)+100*TURN)/SUMYEAR(SIMUL)
5125 RLRAVCOST(TEST,SIMUL)=(RSUMCOST(SIMUL)+100*TURN)/SUMYEAR(SIMUL)
5130 PRINT "LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA =";
5140 PRINT USING"##.###";LRAVCOST(TEST,SIMUL)
5150 PRINT "LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA =";
5160 PRINT USING"##.###";RLRAVCOST(TEST,SIMUL)
5170 PRINT "_______________________________________________________________"
5175 NEXT SIMUL
5180 PRINT
5190 PRINT "  YEARS          REPLACED          CUMULATIVE"
5200 PRINT "FROM - TO        BLDGS(%)          REP. BLDGS(%)"
5210 PRINT "---------        --------          -------------"
5220 CUMTOT=0
5230 FOR I=1 TO SP5
5240 IB=I*5-4 :  IE=I*5
5250 RPBLDG=0
5260 FOR J=IB TO IE
5270 RPBLDG=RPBLDG+REPFQ(J)
5280 NEXT J
5290 RPBLDGP=RPBLDG*100/TURN
5300 CUMTOT=CUMTOT+RPBLDGP
5310 PRINT USING"###";IB;
5320 PRINT " - ";
5330 PRINT USING"###";IE;
5340 PRINT USING"        ###.## ";RPBLDGP,CUMTOT
5350 NEXT I
5360 PRINT USING"###";SP1;
5370 PRINT " -     ";
5380 UNREP=REPFQ(SP1)*100/TURN
5390 CUMTOT=CUMTOT+UNREP
5400 PRINT USING"        ###.## ";UNREP,CUMTOT
5420 RETURN
6000 PRINT
6010 PRINT "________________________________________________________________"
6020 FOR SIMUL=1 TO 6
6030 SPAN=90+10*SIMUL
6040 PRINT "     MAXIMUM LIFE ASSUMED";SPAN;"YEARS"
6050 PRINT "     ------------------------------"
6060 PRINT "MAX REPAIR COST(%)        LONGRUN AVERAGE ANNUAL COST(%)"
6070 PRINT "   TO REPLACE           ABS REPAIR COST   REL REPAIR COST"
6080 PRINT "------------------      ---------------   ---------------"
6090 FOR TEST=1 TO 8
6100 REP%=35+5*TEST
6105 IF TEST=8 THEN REP%=100
6110 PRINT USING"      ###                ";REP%;
6120 PRINT USING"    ##.###          ";LRAVCOST(TEST,SIMUL),RLRAVCOST(TEST,SIMUL)
6130 NEXT TEST
6140 PRINT "________________________________________________________________"
6150 NEXT SIMUL
6160 RETURN
```

Output

```
tail(right) = ? .01
component                  pessimistic   likely    optimistic   eta    sigma
roofing                        10          25          35        3.7     16
ext. cladding                  30          50          70        2.9     23
ext. door/window               30          60         100        2.5     36
ext. finishes                  15          20          25        2.9      5
int. fin.(long)                75         100         150        2.1     34
int. doors                     40          75         125        2.4     43
int. fin.(short)                7          15          25        2.6      9
mech.-moving                   10          15          25        2.1      6
mech.-static                   30          50          80        2.3     25
electrical                     25          50          75        2.9     28
special                        10          30          50        2.9     23
average_excess_cost_of_repair/construction_cost =  1.23657
repair cost (roofing         ) =   4.0% of net_replacement_cost
repair cost (ext. cladding   ) =  11.1% of net_replacement_cost
repair cost (ext. door/window) =  12.7% of net_replacement_cost
repair cost (ext. finishes   ) =   4.0% of net_replacement_cost
repair cost (int. partitions ) =  18.6% of net_replacement_cost
repair cost (int. doors      ) =   3.7% of net_replacement_cost
repair cost (int. finishes   ) =  12.6% of net_replacement_cost
repair cost (mech.-moving    ) =   5.5% of net_replacement_cost
repair cost (mech.-static    ) =   9.6% of net_replacement_cost
repair cost (electrical      ) =   3.3% of net_replacement_cost
repair cost (special         ) =   5.2% of net_replacement_cost
Choose absolute(A) or relative(R) repair cost as a replacement
decision rule. Type A or R.
Replacement decision rule?R
# of simulation =? 2000
DEFINITION ---- NET_REPLACEMENT_COST: Duplication cost excluding
                cost of site work, design and contract overhead.
```

```
          SUMMARY: (RELATIVE) REPAIR COST < 40 %
          ------------------------------------
            AVERAGE LIFE OF BUILDINGS = 47.8
MAXIMUM LIFE ASSUMED 100 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.695
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.890
```

```
MAXIMUM LIFE ASSUMED 110 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.695
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.890
```

```
MAXIMUM LIFE ASSUMED 120 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.695
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.890
```

```
MAXIMUM LIFE ASSUMED 130 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.695
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.890
```

```
MAXIMUM LIFE ASSUMED 140 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.695
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.890
```

```
MAXIMUM LIFE ASSUMED 150 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.695
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.890
```

YEARS FROM - TO	REPLACED BLDGS(%)	CUMULATIVE REP. BLDGS(%)
1 - 5	0.00	0.00
6 - 10	0.00	0.00
11 - 15	0.00	0.00
16 - 20	0.00	0.00
21 - 25	0.00	0.00
26 - 30	0.60	0.60
31 - 35	4.95	5.55
36 - 40	18.35	23.90
41 - 45	27.25	51.15
46 - 50	19.05	70.20
51 - 55	11.50	81.70
56 - 60	6.05	87.75
61 - 65	3.70	91.45
66 - 70	3.45	94.90
71 - 75	2.45	97.35
76 - 80	1.75	99.10
81 - 85	0.55	99.65
86 - 90	0.15	99.80
91 - 95	0.20	100.00
96 - 100	0.00	100.00
101 - 105	0.00	100.00
106 - 110	0.00	100.00
111 - 115	0.00	100.00
116 - 120	0.00	100.00
121 - 125	0.00	100.00
126 - 130	0.00	100.00
131 - 135	0.00	100.00
136 - 140	0.00	100.00
141 - 145	0.00	100.00
146 - 150	0.00	100.00
151 -	0.00	100.00

SUMMARY: (RELATIVE) REPAIR COST < 45 %

AVERAGE LIFE OF BUILDINGS = 54.7

MAXIMUM LIFE ASSUMED 100 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.547
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.800

MAXIMUM LIFE ASSUMED 110 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.546
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.799

MAXIMUM LIFE ASSUMED 120 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.546
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.799

MAXIMUM LIFE ASSUMED 130 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.546
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.799

MAXIMUM LIFE ASSUMED 140 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.546
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.799

MAXIMUM LIFE ASSUMED 150 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.546
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.799

YEARS FROM - TO	REPLACED BLDGS(%)	CUMULATIVE REP. BLDGS(%)
1 - 5	0.00	0.00
6 - 10	0.00	0.00
11 - 15	0.00	0.00
16 - 20	0.00	0.00
21 - 25	0.00	0.00
26 - 30	0.20	0.20
31 - 35	2.00	2.20
36 - 40	10.50	12.70
41 - 45	21.30	34.00
46 - 50	18.70	52.70
51 - 55	12.00	64.70
56 - 60	7.05	71.75
61 - 65	4.55	76.30
66 - 70	5.70	82.00
71 - 75	5.45	87.45
76 - 80	4.25	91.70
81 - 85	3.40	95.10
86 - 90	2.25	97.35
91 - 95	1.70	99.05
96 - 100	0.60	99.65
101 - 105	0.15	99.80
106 - 110	0.15	99.95
111 - 115	0.05	100.00
116 - 120	0.00	100.00
121 - 125	0.00	100.00
126 - 130	0.00	100.00
131 - 135	0.00	100.00
136 - 140	0.00	100.00
141 - 145	0.00	100.00
146 - 150	0.00	100.00
151 -	0.00	100.00

SUMMARY: (RELATIVE) REPAIR COST < 50 %

AVERAGE LIFE OF BUILDINGS = 64.3

MAXIMUM LIFE ASSUMED 100 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.405
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.729

MAXIMUM LIFE ASSUMED 110 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.401
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.726

MAXIMUM LIFE ASSUMED 120 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.400
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.725

MAXIMUM LIFE ASSUMED 130 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.400
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.725

MAXIMUM LIFE ASSUMED 140 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.400
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.725

MAXIMUM LIFE ASSUMED 150 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.400
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.725

YEARS FROM - TO	REPLACED BLDGS(%)	CUMULATIVE REP. BLDGS(%)
1 - 5	0.00	0.00
6 - 10	0.00	0.00
11 - 15	0.00	0.00
16 - 20	0.00	0.00
21 - 25	0.00	0.00
26 - 30	0.00	0.00
31 - 35	0.90	0.90
36 - 40	5.60	6.50
41 - 45	13.75	20.25
46 - 50	12.75	33.00
51 - 55	9.05	42.05
56 - 60	7.15	49.20
61 - 65	4.15	53.35
66 - 70	6.50	59.85
71 - 75	8.55	68.40
76 - 80	7.80	76.20
81 - 85	7.95	84.15
86 - 90	6.70	90.85
91 - 95	4.30	95.15
96 - 100	2.10	97.25
101 - 105	1.10	98.35
106 - 110	0.85	99.20
111 - 115	0.35	99.55
116 - 120	0.35	99.90
121 - 125	0.05	99.95
126 - 130	0.05	100.00
131 - 135	0.00	100.00
136 - 140	0.00	100.00
141 - 145	0.00	100.00
146 - 150	0.00	100.00
151 -	0.00	100.00

SUMMARY: (RELATIVE) REPAIR COST < 55 %

AVERAGE LIFE OF BUILDINGS = 74.2
MAXIMUM LIFE ASSUMED 100 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.312
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.694

MAXIMUM LIFE ASSUMED 110 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.303
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.687

MAXIMUM LIFE ASSUMED 120 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.301
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.686

MAXIMUM LIFE ASSUMED 130 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.298
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.684

MAXIMUM LIFE ASSUMED 140 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.296
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.683

MAXIMUM LIFE ASSUMED 150 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.295
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.683

YEARS FROM - TO	REPLACED BLDGS(%)	CUMULATIVE REP. BLDGS(%)
1 - 5	0.00	0.00
6 - 10	0.00	0.00
11 - 15	0.00	0.00
16 - 20	0.00	0.00
21 - 25	0.00	0.00
26 - 30	0.00	0.00
31 - 35	0.15	0.15
36 - 40	2.05	2.20
41 - 45	8.05	10.25
46 - 50	8.90	19.15
51 - 55	7.40	26.55
56 - 60	4.40	30.95
61 - 65	3.80	34.75
66 - 70	5.65	40.40
71 - 75	7.60	48.00
76 - 80	8.85	56.85
81 - 85	10.85	67.70
86 - 90	11.80	79.50
91 - 95	8.45	87.95
96 - 100	4.65	92.60
101 - 105	2.35	94.95
106 - 110	1.70	96.65
111 - 115	0.95	97.60
116 - 120	0.55	98.15
121 - 125	0.35	98.50
126 - 130	0.25	98.75
131 - 135	0.10	98.85
136 - 140	0.10	98.95
141 - 145	0.05	99.00
146 - 150	0.05	99.05
151 -	0.95	100.00

SUMMARY: (RELATIVE) REPAIR COST < 60 %

AVERAGE LIFE OF BUILDINGS = 85.0
MAXIMUM LIFE ASSUMED 100 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.248
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.675

MAXIMUM LIFE ASSUMED 110 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.233
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.666

MAXIMUM LIFE ASSUMED 120 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.227
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.664

MAXIMUM LIFE ASSUMED 130 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.220
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.661

MAXIMUM LIFE ASSUMED 140 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.214
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.658

MAXIMUM LIFE ASSUMED 150 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.209
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.656

YEARS FROM - TO	REPLACED BLDGS(%)	CUMULATIVE REP. BLDGS(%)
1 - 5	0.00	0.00
6 - 10	0.00	0.00
11 - 15	0.00	0.00
16 - 20	0.00	0.00
21 - 25	0.00	0.00
26 - 30	0.00	0.00
31 - 35	0.05	0.05
36 - 40	0.75	0.80
41 - 45	3.70	4.50
46 - 50	5.30	9.80
51 - 55	3.20	13.00
56 - 60	2.05	15.05
61 - 65	2.50	17.55
66 - 70	4.15	21.70
71 - 75	8.45	30.15
76 - 80	8.65	38.80
81 - 85	12.00	50.80
86 - 90	13.20	64.00
91 - 95	11.35	75.35
96 - 100	8.20	83.55
101 - 105	4.90	88.45
106 - 110	2.70	91.15
111 - 115	1.40	92.55
116 - 120	0.65	93.20
121 - 125	0.45	93.65
126 - 130	0.30	93.95
131 - 135	0.35	94.30
136 - 140	0.20	94.50
141 - 145	0.20	94.70
146 - 150	0.15	94.85
151 -	5.15	100.00

SUMMARY: (RELATIVE) REPAIR COST < 65 %

AVERAGE LIFE OF BUILDINGS = 99.2
MAXIMUM LIFE ASSUMED 100 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.225
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.698

MAXIMUM LIFE ASSUMED 110 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.201
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.688

MAXIMUM LIFE ASSUMED 120 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.188
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.686

MAXIMUM LIFE ASSUMED 130 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.171
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.677

MAXIMUM LIFE ASSUMED 140 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.159
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.673

MAXIMUM LIFE ASSUMED 150 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.145
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.666

YEARS FROM - TO	REPLACED BLDGS(%)	CUMULATIVE REP. BLDGS(%)
1 - 5	0.00	0.00
6 - 10	0.00	0.00
11 - 15	0.00	0.00
16 - 20	0.00	0.00
21 - 25	0.00	0.00
26 - 30	0.00	0.00
31 - 35	0.00	0.00
36 - 40	0.10	0.10
41 - 45	1.35	1.45
46 - 50	2.70	4.15
51 - 55	1.75	5.90
56 - 60	1.10	7.00
61 - 65	1.35	8.35
66 - 70	2.65	11.00
71 - 75	4.95	15.95
76 - 80	5.35	21.30
81 - 85	8.25	29.55
86 - 90	14.85	44.40
91 - 95	13.30	57.70
96 - 100	8.55	66.25
101 - 105	5.55	71.80
106 - 110	3.50	75.30
111 - 115	2.40	77.70
116 - 120	1.60	79.30
121 - 125	0.80	80.10
126 - 130	0.50	80.60
131 - 135	0.90	81.50
136 - 140	0.70	82.20
141 - 145	0.55	82.75
146 - 150	0.40	83.15
151 -	16.85	100.00

SUMMARY: (RELATIVE) REPAIR COST < 70 %

AVERAGE LIFE OF BUILDINGS =113.8

MAXIMUM LIFE ASSUMED 100 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.217
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.723

MAXIMUM LIFE ASSUMED 110 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.189
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.718

MAXIMUM LIFE ASSUMED 120 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.170
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.718

MAXIMUM LIFE ASSUMED 130 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.141
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.701

MAXIMUM LIFE ASSUMED 140 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.120
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.694

MAXIMUM LIFE ASSUMED 150 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.103
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.689

YEARS FROM - TO	REPLACED BLDGS(%)	CUMULATIVE REP. BLDGS(%)
1 - 5	0.00	0.00
6 - 10	0.00	0.00
11 - 15	0.00	0.00
16 - 20	0.00	0.00
21 - 25	0.00	0.00
26 - 30	0.00	0.00
31 - 35	0.00	0.00
36 - 40	0.05	0.05
41 - 45	0.40	0.45
46 - 50	0.95	1.40
51 - 55	0.85	2.25
56 - 60	0.25	2.50
61 - 65	0.35	2.85
66 - 70	1.05	3.90
71 - 75	2.65	6.55
76 - 80	4.60	11.15
81 - 85	6.10	17.25
86 - 90	10.45	27.70
91 - 95	11.50	39.20
96 - 100	8.10	47.30
101 - 105	5.85	53.15
106 - 110	3.20	56.35
111 - 115	2.50	58.85
116 - 120	1.10	59.95
121 - 125	1.45	61.40
126 - 130	0.85	62.25
131 - 135	0.85	63.10
136 - 140	0.80	63.90
141 - 145	0.60	64.50
146 - 150	0.25	64.75
151 -	35.25	100.00

SUMMARY: (RELATIVE) REPAIR COST < 100 %

AVERAGE LIFE OF BUILDINGS =150.6

MAXIMUM LIFE ASSUMED 100 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.264
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.835

MAXIMUM LIFE ASSUMED 110 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.245
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.866

MAXIMUM LIFE ASSUMED 120 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.210
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.867

MAXIMUM LIFE ASSUMED 130 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.153
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.829

MAXIMUM LIFE ASSUMED 140 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.115
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.812

MAXIMUM LIFE ASSUMED 150 YEARS
LONG RUN AVERAGE ANNUAL COST (%) OF RPMA & MCA = 3.081
LONG RUN AVG. ANN. COST (%) OF REL. RPMA & MCA = 3.796

YEARS FROM - TO	REPLACED BLDGS(%)	CUMULATIVE REP. BLDGS(%)
1 - 5	0.00	0.00
6 - 10	0.00	0.00
11 - 15	0.00	0.00
16 - 20	0.00	0.00
21 - 25	0.00	0.00
26 - 30	0.00	0.00
31 - 35	0.00	0.00
36 - 40	0.00	0.00
41 - 45	0.00	0.00
46 - 50	0.00	0.00
51 - 55	0.00	0.00
56 - 60	0.00	0.00
61 - 65	0.00	0.00
66 - 70	0.00	0.00
71 - 75	0.00	0.00
76 - 80	0.00	0.00
81 - 85	0.05	0.05
86 - 90	0.10	0.15
91 - 95	0.10	0.25
96 - 100	0.25	0.50
101 - 105	0.25	0.75
106 - 110	0.05	0.80
111 - 115	0.00	0.80
116 - 120	0.00	0.80
121 - 125	0.00	0.80
126 - 130	0.00	0.80
131 - 135	0.05	0.85

136 - 140	0.00	0.85
141 - 145	0.00	0.85
146 - 150	0.05	0.90
151 -	99.10	100.00

MAXIMUM LIFE ASSUMED 100 YEARS

MAX REPAIR COST(%) TO REPLACE	LONGRUN AVERAGE ABS REPAIR COST	ANNUAL COST(%) REL REPAIR COST
40	3.695	3.890
45	3.547	3.800
50	3.405	3.729
55	3.312	3.694
60	3.248	3.675
65	3.225	3.698
70	3.217	3.723
100	3.264	3.835

MAXIMUM LIFE ASSUMED 110 YEARS

MAX REPAIR COST(%) TO REPLACE	LONGRUN AVERAGE ABS REPAIR COST	ANNUAL COST(%) REL REPAIR COST
40	3.695	3.890
45	3.546	3.799
50	3.401	3.726
55	3.303	3.687
60	3.233	3.666
65	3.201	3.688
70	3.189	3.718
100	3.245	3.866

MAXIMUM LIFE ASSUMED 120 YEARS

MAX REPAIR COST(%) TO REPLACE	LONGRUN AVERAGE ABS REPAIR COST	ANNUAL COST(%) REL REPAIR COST
40	3.695	3.890
45	3.546	3.799
50	3.400	3.725
55	3.301	3.686
60	3.227	3.664
65	3.188	3.686
70	3.170	3.718
100	3.210	3.867

MAXIMUM LIFE ASSUMED 130 YEARS

MAX REPAIR COST(%) TO REPLACE	LONGRUN AVERAGE ABS REPAIR COST	ANNUAL COST(%) REL REPAIR COST
40	3.695	3.890
45	3.546	3.799
50	3.400	3.725
55	3.298	3.684
60	3.220	3.661
65	3.171	3.677
70	3.141	3.701

100	3.153	3.829

MAXIMUM LIFE ASSUMED 140 YEARS

MAX REPAIR COST(%) TO REPLACE	LONGRUN AVERAGE ABS REPAIR COST	ANNUAL COST(%) REL REPAIR COST
40	3.695	3.890
45	3.546	3.799
50	3.400	3.725
55	3.296	3.683
60	3.214	3.658
65	3.159	3.673
70	3.120	3.694
100	3.115	3.812

MAXIMUM LIFE ASSUMED 150 YEARS

MAX REPAIR COST(%) TO REPLACE	LONGRUN AVERAGE ABS REPAIR COST	ANNUAL COST(%) REL REPAIR COST
40	3.695	3.890
45	3.546	3.799
50	3.400	3.725
55	3.295	3.683
60	3.209	3.656
65	3.145	3.666
70	3.103	3.689
100	3.081	3.796

APPENDIX C:

SIMULATION III—FACILITY MANAGEMENT COST PREDICTION MODEL FOR TRADOC

Program

```
10  SPN=260
20  FYR=148
30  SP1=SPN+1
40  DIM PYRCOST(SP1),REPFQ(SP1),RPMA(SPN),TRPMA(SPN),RPMAPCT(SPN),XTWICE(SP1)
50  DIM XRTWICE(SP1),COMP$(11),OPT(11),MOST(11),PESS(11),ETA1(11),SIGMA(11)
55  DIM COMPCOST(11),REPCOST(11),REPCOSTP(11),ACTVALUE(SP1),CONAREA(185)
56  DIM BDAGE(SPN),TBDAGE(SPN)
60  REM    SIMULATION MODEL: FORECAST FOR MCA and RPMA COST IN TRADOC
70  REM                      YEARS OF FORECAST --- 1988 TO 2100
80  REM       (1) LIFE OF A BUILDING IS ESTIMATED BY SIMULATING THE LIFE OF EACH
90  REM           BUILDING COMPONENT.
100 REM       (2) THE LIFE LENGTH OF A BUILDING COMPONENT IS ASSUMED FOLLOWING
110 REM           WEIBULL DISTRIBUTION.
120 REM       (3) TO DETERMINE THE PARAMETERS IN WEIBULL DISTRIBUTION OF A
130 REM           COMPONENT, THE LIFE OF A COMPONENT IS ESTIMATED BY THREE WAYS,
140 REM           I.E., OPTIMISTIC, PESSIMISTIC AND MOST LIKELY LIFE LENGTH.
150 REM           (ASSUMPTION IN WEIBULL PARAMETER GENERATION: (a) a component
160 REM           never fails earlier than its pessimistic life length.
170 REM           (b) A probability of a component failure after its optimistic
180 REM           life is less than a given value; this value should be given
190 REM           as an input (TAIL_RIGHT) at the beginning. TAIL_RIGHT = 0.01
200 REM           is recommended.)
201 REM       (4) REPAIR COST OF EACH COMPONENT VARIES UNIFORMLY WITHIN THE
202 REM           RANGE OF PLUS AND TEN PER CENT OF ITS AVERAGE REPAIR COST.
210 REM
220 REM     SUBROUTINE 3000: TO ESTIMATES THE VALUES OF sigma (scale
230 REM           parameter) and eta (shape parameter) in weibull distribution
240 REM
250 REM     SUBROUTINE 4000: TO PROVIDE INPUT DATA OF COMPONENT COST.
260 REM
261 REM     SUBROUTINE 4800: TO GENERATE FACILITY INVENTORY PROFILE.
262 REM
265 REM     SUBROUTINE 5000: TO GENERATE THE OUTPUT.
266 REM
270 REM     ASSUMPTION: MARGINAL CONDITION OF A COMPONENT
280 REM           IF REMAINING LIFE OF A COMPONENT IS LESS THAN 25 PER CENT OF
290 REM           ITS NATURAL LIFE, THE CONDITION OF THE COMPONENT IS ASSUMED
300 REM           MARGINAL.
310 REM
320 REM    DECISION RULE OF BUILDING REPLACEMENT:
330 REM          IF SEVERAL COMPONENTS ARE IN MARGINAL CONDITION AND REPAIR
340 REM          COSTS FOR THESE COMPONENTS EXCEEDS SOME LIMIT IN A CERTAIN
350 REM          YEAR, THEN THE WHOLE BUILDING IS REPLACED.  OTHERWISE, EACH
360 REM          COMPONENT IS USED UNTIL IT FAILS.
370 REM
380 REM    DEFINITION: NET_REPLACEMENT_COST
390 REM          NET REPLACEMENT COST of a building is the cost of duplication
400 REM          EXCLUDING costs of site work, design and contract overhead.
401 REM
402 REM    DEFINITION: RENOVATED VALUE
403 REM          RENOVATED VALUE OF A BUILDING is net replacement cost minus
404 REM          depreciated cost of unreplacable components, e.g., frame
405 REM          and foundation.
406 REM
410 GOSUB 3000
420 GOSUB 4000
425 GOSUB 4500
426 GOSUB 4800
```

```
430 RANDOMIZE TIMER
440 PRINT "DEFINITION ---- NET_REPLACEMENT_COST: Duplication cost excluding
450 PRINT "                cost of site work, design and contract overhead."
455 PRINT "                RENOVATED VALUE: net replacement cost of a building"
456 PRINT "                less depreciation of unreplacable components."
470 PRINT
480 INPUT "Building is replaced when relative repair cost is more than ",REP%
490 PRINT "per cent of the renovated value of a building."
500 PRINT
510 SIMUL=5
515 TURN=1000
520 TAREA=0
530 IF REP%<66 THEN EARLY=22 ELSE EARLY=30
535 FOR SML=1 TO SIMUL
540 FOR ITURN=1 TO TURN
550 READ YRBUILT,SF
555 IF YRBUILT=0 THEN 1240
560 BLDGX%=SF/5 : REM --- EACH UNIT OF HOUSING COMPLEX IS CONSIDERED 5K SQ.FT.
570 IF BLDGX%<1 THEN 550
580 FOR BN=1 TO BLDGX%
590 YRZERO=YRBUILT-40  : REM --- A HOUSE BUILT IN 1840 IS INPUTTED AS 40 IN
600 REM                     DATA BUT CONSIDERED YEAR 0 IN THE PROGRAM
640 FOR RY=YRZERO TO SP1 : PYRCOST(RY)=0 : NEXT RY
650 FOR RP=YRZERO TO SPN : RPMA(RP)=0 :NEXT RP
660 FOR RX=YRZERO TO SP1 : XTWICE(RX)=0 : XRTWICE(RX)=0 : NEXT RX
665 FOR RA=YRZERO TO SPN : BDAGE(RA)=RA-YRZERO : NEXT RA
670 FOR C=1 TO 11
680 YRREP=YRZERO
690 REM -------- following function generates a life of component by weibull
700 REM          distribution.
710 PESSC=PESS(C) : SIGMAC=SIGMA(C) : ETA1C=ETA1(C)
720 RPCP=REPCOSTP(C)*(.9+.2*RND)
723 RRD=RND
725 OVFL=10^(-38)
726 IF RRD<OVFL THEN RRD=OVFL
730 FAILTIM=PESSC+SIGMAC*(-LOG(RRD))^(1/ETA1C)
740 YRFAIL=INT(FAILTIM)
750 YRREP=YRREP+YRFAIL                : REM --- year of component failure
760 IF YRREP<FYR THEN 723
770 BYRMAR=YRREP+1-INT(YRFAIL*.25)    : REM --- biginning year of marginal cond.
780 IF BYRMAR>SPN THEN 930
790 IF YRREP>SPN THEN 840
800 REM -------- Repair cost of a component
810 IF C=2 THEN XRTWICE(YRREP)=1 : REM --- To eliminate major double counting
820 IF C=4 AND XRTWICE(YRREP)=1 THEN 870
830 RPMA(YRREP)=RPMA(YRREP)+RPCP
840 IF YRREP>SPN THEN YRREP=SP1
850 REM -------- Following function generates potential repair costs of
860 REM          compenents which are in marginal condition.
870 FOR MAR=BYRMAR TO YRREP
880 IF C=2 THEN XTWICE(MAR)=1              : REM --- To eliminate major double
890 IF C=4 AND XTWICE(MAR)=1 THEN 910      : REM     counting in costs est.
900 PYRCOST(MAR)=PYRCOST(MAR)+RPCP/ACTVALUE(MAR-YRZERO)
910 NEXT MAR
920 GOTO 723
930 NEXT C
940 REM -------- Following routine simulates a time of replacement.
950 REPYEAR=SP1
960 Y1=EARLY+YRZERO
970 FOR Y=Y1 TO SP1
980 IF PYRCOST(Y)<REP% THEN 1010
990 PREPY=Y
```

```
995 IF PREPY=SP1 THEN 1180
1000 GOTO 1040
1010 NEXT Y
1030 GOTO 1180
1040 PEAKSAVE=PYRCOST(PREPY)
1050 YBG=PREPY+1
1060 REM --- To postpone the replacement as long as possible under the rule.
1070 FOR K=YBG TO SP1
1080 IF PYRCOST(K)>=PEAKSAVE THEN 1110
1090 REPYEAR=K-1
1100 GOTO 1130
1110 PEAKSAVE=PYRCOST(K)
1120 NEXT K
1130 REPFQ(REPYEAR)=REPFQ(REPYEAR)+1     : REM --- annual new construction
1140 REM -------- New repair cycle begins after the replacement
1150 YRZERO=REPYEAR
1160 GOTO 640
1170 REM -------- Annual cost of repair estimation
1180 FOR YR=FYR TO SPN
1190 TRPMA(YR)=TRPMA(YR)+RPMA(YR)
1195 TBDAGE(YR)=TBDAGE(YR)+BDAGE(YR)
1200 NEXT YR
1210 NEXT BN
1220 TAREA=TAREA+5*BLDGX%  : REM --- SUMMING UP TOTAL AREA OF BUILDINGS
1230 NEXT ITURN
1240 RESTORE 6000
1250 NEXT SML
1300 GOSUB 5000 : REM --- TO GENERATE OUTPUT
2990 END
3000 REM -------- "ESTIMATION OF WEIBULL DISTRIBUTION"
3010 REM
3030 INPUT "tail(right) = ";RTAIL
3040 X=LOG(RTAIL)
3050 XX=LOG(-X)
3060 PRINT "component              pessimistic   likely    optimistic    eta    sig
3070 FOR I=1 TO 11 : READ COMP$(I) : NEXT I
3080 FOR I=1 TO 11 : READ OPT(I) : NEXT I
3090 FOR I=1 TO 11 : READ MOST(I) : NEXT I
3100 FOR I=1 TO 11 : READ PESS(I) : NEXT I
3110 FOR CP=1 TO 11
3120 MODE=MOST(CP)-PESS(CP)
3130 TOPT=OPT(CP)-PESS(CP)
3140 RATIO=TOPT/MODE
3150 FOR TA=0 TO 100
3160 ETA=2+.1*TA
3170 TEST=ETA*LOG(RATIO)-LOG(ETA)+LOG(ETA-1)-XX
3180 IF TEST>0 THEN 3200
3190 NEXT TA
3200 RETA=1/ETA
3210 DIV=((ETA-1)/ETA)^RETA
3220 SGMA=MODE/DIV
3230 SIGMA(CP)=INT(SGMA)
3240 ETA1(CP)=ETA
3250 PRINT COMP$(CP);"    ";
3260 PRINT USING"     ###     ";PESS(CP);MOST(CP);OPT(CP);
3270 PRINT USING"    #.#    ";ETA1(CP);
3280 PRINT USING "  ### ";SIGMA(CP)
3290 NEXT CP
3300 DATA "roofing          ","ext. cladding    ","ext. door/window"
3310 DATA "ext. finishes    ","int. partitions ","int. doors      "
```

```
3320 DATA "int. finishes     ","mech.-moving     ","mech.-static     "
3330 DATA "electrical        ","special          "
3340 DATA 35,70,100,25,150,125,25,25,80,75,50
3350 DATA 25,50,60,20,100,75,15,15,50,50,30
3360 DATA 10,30,30,15,75,40,7,10,30,25,10
3370 RETURN
4000 REM "generation of cost data for the replacement of a component"
4010 REM  Most of the repair works requires more cost than construction:
4020 REM      Repair jobs might acompany with some side effects, i.e., plumbing
4030 REM      job frequently damages wall or floor, and require extra labor
4040 REM      to remove the failed components.
4060 FOR I=1 TO 11 : READ COMPCOST(I) : NEXT I
4070 FOR I=1 TO 11 : REPCOST(I)=COMPCOST(I) : NEXT I
4080 REPCOST(1)=1.1*COMPCOST(1)
4090 REPCOST(2)=1.1*COMPCOST(2)+COMPCOST(4)+.05*COMPCOST(10)
4100 REPCOST(3)=1.05*COMPCOST(3)+.05*COMPCOST(4)+.05*COMPCOST(7)
4110 REPCOST(4)=1.5*COMPCOST(4)+.05*COMPCOST(10)
4120 REPCOST(5)=COMPCOST(5)+.15*COMPCOST(10)+.35*COMPCOST(7)
4130 REPCOST(9)=1.3*COMPCOST(9)+.15*COMPCOST(5)+.03*COMPCOST(7)
4140 REPCOST(10)=COMPCOST(10)+.05*COMPCOST(5)+.01*COMPCOST(7)
4150 REPCOST(11)=COMPCOST(11)+.05*COMPCOST(5)+.02*COMPCOST(9)+.02*COMPCOST(10)
4160 REPCOST(11)=REPCOST(11)+.01*COMPCOST(7)
4170 TREPCOST=0
4180 COSTFDN=3.96 : REM --- cost of foundation ($/sq.ft)
4190 COSTFRM=5.45 : REM --- cost of framing ($/sq.ft)
4200 OVERCOST=COSTFDN+COSTFRM
4210 TCONCOST=0
4220 FOR I=1 TO 11
4230 TREPCOST=TREPCOST+REPCOST(I)
4240 NEXT I
4250 FOR I=1 TO 11
4260 TCONCOST=TCONCOST+COMPCOST(I)
4270 NEXT I
4280 REPCON=TREPCOST/TCONCOST
4290 PRINT "average_excess_cost_of_repair/construction_cost = ";REPCON
4300 TCONCOST=TCONCOST+OVERCOST
4310 FOR I=1 TO 11 : REPCOSTP(I)=REPCOST(I)*100/TCONCOST : NEXT I
4320 FOR I=1 TO 11
4330 PRINT "repair cost (";COMP$(I);") = ";
4340 PRINT USING" ##.#";REPCOSTP(I);
4350 PRINT "% of net_replacement_cost"
4360 NEXT I
4370 DATA 1.25,2.66,3.96,0.9,4.82,1.28,4.4,1.9,1.9,.85,1.47
4380 RETURN
4500 REM --- THIS SUBROUTINE GENERATES THE RELATIVE WORTH OF AN OLD FACILITY TO
4510 REM     THE NEW ONE.  LINEAR DEPRECIATION IS ASSUMED.
4520 ANNDEP=OVERCOST/(TCONCOST*75)
4530 FOR Y=1 TO 75
4540 ACTVALUE(Y)=1-Y*ANNDEP
4550 NEXT Y
4555 FOR Y=76 TO SP1 : ACTVALUE(Y)=ACTVALUE(75) : NEXT Y
4560 RETURN
4800 REM --- To generate facility inventory profile
4801 PRINT
4802 PRINT
4803 PRINT "         ________________________________"
4805 PRINT "         FAMILY HOUSING INVENTORY PROFILE"
4810 PRINT "______________________________________________________________"
4815 PRINT "CONSTRUCTION YEAR                GROSS AREA         "
4816 PRINT "   FROM     TO              (K.SQ.FT)  (% OF TOTAL)"
```

```
4820 PRINT "-----------------        ---------   ------------"
4830 FOR Y=1 TO 185 : CONAREA(Y)=0 : NEXT Y
4831 GSF=0
4835 FOR I=1 TO 1000
4840 READ YRBUILT,SF
4843 IF YRBUILT=0 THEN 4860
4845 CONAREA(YRBUILT)=CONAREA(YRBUILT)+SF
4846 GSF=GSF+SF
4850 NEXT I
4860 FOR Y=1 TO 29
4885 BY=41+(Y-1)*5 : BE=BY+4
4890 PAREA=0
4900 FOR Y5=BY TO BE
4905 PAREA=PAREA+CONAREA(Y5)
4910 NEXT Y5
4912 PROAREA=100*PAREA/GSF
4915 YS=1800+BY : YF=1800+BE
4920 PRINT "   ";YS;"-";YF;
4925 PRINT USING"           #####  ";PAREA;
4926 PRINT USING"       ##.##";PROAREA
4930 NEXT Y
4931 PRINT "                           -------"
4932 PRINT "INVENTORY BUILT 1841-1985:";GSF
4935 RESTORE 6000
4940 PRINT
4945 PRINT
4950 RETURN
5000 REM -------- OUTPUT GENERATION
5010 REM
5020 PRINT "____________________________________________________________________________"
5030 PRINT
5040 PRINT " 1988-2100 FAMILY HOUSING COST FORECAST FOR REPAIR AND REPLACEMENT"
5045 PRINT "                    IN TRAINING AND DOCTRINE COMMAND"
5050 PRINT "_____________________________________________________________________________"
5055 NAREA=TAREA/SIMUL
5056 BKAREA=NAREA+1304
5057 ADJ=BKAREA/NAREA
5060 PRINT " TOTAL AREA (RAW DATA) =";NAREA;"KILO SQUARE FEET"
5065 PRINT "       (ADJUSTED DATA) =";BKAREA;"KILO SQUARE FEET"
5070 PRINT "____________________________________________________________________________"
5080 PRINT
5090 PRINT "YEAR   COST (% OF CONSTR. COST)  COST(KSF. BLDG.EQ.)   CONSTR  AVG"
5100 PRINT "     ---------------------------  -------------------    OVER   AGE"
5110 PRINT "        REPAIR      CONSTRUCTION  REPAIR CONSTR TOTAL   REPAIR   OF"
5115 PRINT "     ANNUAL CUMUL  ANNUAL CUMUL    COST   COST   COST     (%)   BLDG"
5120 PRINT "---- ------ ------ ------ ------ ------ ------ ------   ------  ----"
5190 TAREA5=TAREA/5
5195 SRPMAPC=0 : SMCAPC=0 : SMCAEQ=0
5196 HOR=SPN-FYR+1
5200 FOR Y=FYR TO SPN
5210 MCAPC=100*REPFQ(Y)/TAREA5
5215 SMCAPC=SMCAPC+MCAPC
5220 RPMAPC=TRPMA(Y)/TAREA5
5225 SRPMAPC=SRPMAPC+RPMAPC
5230 RPMAEQ=ADJ*TRPMA(Y)*5/(100*SIMUL)
5240 MCAEQ=ADJ*REPFQ(Y)*5/SIMUL
5243 AVGAGE=TBDAGE(Y)/TAREA5
5245 SMCAEQ=SMCAEQ+MCAEQ
5250 TOTEQ=RPMAEQ+MCAEQ
5260 RMRATIO=100*MCAEQ/RPMAEQ
5270 FYEAR=Y+1840
5280 PRINT USING"#### ";FYEAR;
5290 PRINT USING"###.## ";RPMAPC,SRPMAPC,MCAPC,SMCAPC;
5310 PRINT USING" ##### ";RPMAEQ,MCAEQ,TOTEQ;
5320 PRINT USING" ###.##";RMRATIO;
5330 PRINT USING"  ##.#";AVGAGE
```

```
5400 NEXT Y
5410 SMCAPC=SMCAPC/HOR
5420 SRPMAPC=SRPMAPC/HOR
5430 SMCAEQ=SMCAEQ/HOR
5440 SRMRATIO=SRPMAPC/SMCAPC
5445 VARRPMA=0 : VARMCA=0
5447 FOR Y=FYR TO SPN
5450 VARRPMA=VARRPMA+(TRPMA(Y)/TAREA5-SRPMAPC)^2
5452 VARMCA=VARMCA+(100*REPFQ(Y)/TAREA5-SMCAPC)^2
5455 NEXT Y
5457 STDRPMA=(VARRPMA/HOR)^.5
5458 STDMCA=(VARMCA/HOR)^.5
5460 PRINT "______________________________________________________________"
5470 PRINT "             SUMMARY STATISTICS FOR 1988-2100"
5480 PRINT "             --------------------------------"
5490 PRINT "ANNUAL AVERAGE REPAIR COST AS % OF CONSTRUCTION COST =";
5500 PRINT USING"##.##";SRPMAPC
5505 PRINT "       STANDARD DEVIATION OF ANNUAL REPAIR COST (%) =";
5506 PRINT USING"##.##";STDRPMA
5510 PRINT "ANNUAL AVERAGE REPLACEMENT COST(%) OUT OF TOTAL BLDG =";
5520 PRINT USING"##.##";SMCAPC
5525 PRINT "   STANDARD DEVIATION OF ANNUAL REPLACEMENT COST (%) =";
5526 PRINT USING"##.##";STDMCA
5530 PRINT "ANNUAL AVERAGE REPLACED BUILDINGS IN KILO SQUARE FT. =";
5540 PRINT USING"####.#";SMCAEQ
5550 PRINT "ANNUAL AVERAGE REPAIR COST/ AVERAGE REPLACEMENT COST =";
5560 PRINT USING"##.##";SRMRATIO
5600 RETURN
5990 REM ------ CONSTRUCTION DATA ENTRY BY CONSTRUCTION YEAR AND KILO SQ. FT.
6000 DATA 40,74,41,10,55,18,56,8,63,20,64,10,65,5,70,107
6010 DATA 75,20,78,22,80,3,83,21,86,12,87,4,89,58,90,24,91,16
6020 DATA 92,69,93,40,94,47,95,4,97,9,98,11,100,1,101,87,103,442
6030 DATA 104,7,105,115,106,232,107,20,108,282,109,181,110,5,111,227
6040 DATA 114,44,115,7,116,2,117,10,118,13,119,3,120,69,121,15,122,12
6050 DATA 123,184,124,42,126,5,128,17,130,443,131,423,132,206,133,135
6060 DATA 134,1648,135,346,136,120,137,21,138,116,139,572,140,227
6070 DATA 141,27,142,234,143,13,145,1,146,24,147,239,148,96,149,6
6080 DATA 150,590,151,3088,152,2022,153,463,155,183,156,1169,157,2443
6090 DATA 158,5964,159,4990,160,3570,161,1983,162,2916,163,1122,164,309
6100 DATA 165,7,166,315,167,318,168,270,169,453,170,1203,171,276,172,1179
6110 DATA 173,1,174,511,175,894,176,5,180,200,181,550
9990 DATA 0,0
```

Output (50 Percent RRC Criterion)

```
tail(right) = ? .01
component              pessimistic   likely   optimistic   eta   sigma
roofing                    10          25         35        3.7    16
ext. cladding              30          50         70        2.9    23
ext. door/window           30          60        100        2.5    36
ext. finishes              15          20         25        2.9     5
int. fin.(long)            75         100        150        2.1    34
int. doors                 40          75        125        2.4    43
int. fin.(short)            7          15         25        2.6     9
mech.-moving               10          15         25        2.1     6
mech.-static               30          50         80        2.3    25
electrical                 25          50         75        2.9    28
special                    10          30         50        2.9    23
average_excess_cost_of_repair/construction_cost =  1.23657
repair cost (roofing         ) =   4.0% of net_replacement_cost
repair cost (ext. cladding   ) =  11.1% of net_replacement_cost
repair cost (ext. door/window) =  12.7% of net_replacement_cost
repair cost (ext. finishes   ) =   4.0% of net_replacement_cost
repair cost (int. partitions ) =  18.6% of net_replacement_cost
```

repair cost (int. doors) = 3.7% of net_replacement_cost
repair cost (int. finishes) = 12.6% of net_replacement_cost
repair cost (mech.-moving) = 5.5% of net_replacement_cost
repair cost (mech.-static) = 9.6% of net_replacement_cost
repair cost (electrical) = 3.3% of net_replacement_cost
repair cost (special) = 5.2% of net_replacement_cost

FAMILY HOUSING INVENTORY PROFILE

CONSTRUCTION YEAR FROM	TO	GROSS AREA (K.SQ.FT)	(% OF TOTAL)
1841	1845	10	0.02
1846	1850	0	0.00
1851	1855	18	0.04
1856	1860	8	0.02
1861	1865	35	0.08
1866	1870	107	0.24
1871	1875	20	0.04
1876	1880	25	0.06
1881	1885	21	0.05
1886	1890	98	0.22
1891	1895	176	0.40
1896	1900	21	0.05
1901	1905	651	1.46
1906	1910	720	1.62
1911	1915	278	0.62
1916	1920	97	0.22
1921	1925	253	0.57
1926	1930	465	1.04
1931	1935	2758	6.19
1936	1940	1056	2.37
1941	1945	275	0.62
1946	1950	955	2.14
1951	1955	5756	12.93
1956	1960	18136	40.73
1961	1965	6337	14.23
1966	1970	2559	5.75
1971	1975	2861	6.43
1976	1980	205	0.46
1981	1985	550	1.24

INVENTORY BUILT 1841-1985: 44525

DEFINITION ---- NET_REPLACEMENT_COST: Duplication cost excluding cost of site work, design and contract overhead.
RENOVATED VALUE: net replacement cost of a building less depreciation of unreplacable components.

Building is replaced when relative repair cost is more than 50 per cent of the renovated value of a building.

1988-2100 FAMILY HOUSING COST FORECAST FOR REPAIR AND REPLACEMENT IN TRAINING AND DOCTRINE COMMAND

TOTAL AREA (RAW DATA) = 44520 KILO SQUARE FEET
(ADJUSTED DATA) = 45824 KILO SQUARE FEET

YEAR	COST (% OF CONSTR. COST)				COST(KSF. BLDG.EQ.)			CONSTR OVER REPAIR	AVG AGE OF BLDG
	REPAIR		CONSTRUCTION		REPAIR	CONSTR	TOTAL		
	ANNUAL	CUMUL	ANNUAL	CUMUL	COST	COST	COST	(%)	
1988	2.05	2.05	0.81	0.81	939	372	1311	39.57	33.4
1989	2.08	4.12	0.82	1.64	951	378	1329	39.73	33.9
1990	2.02	6.14	0.80	2.43	925	364	1289	39.41	34.3
1991	1.94	8.09	0.73	3.16	891	332	1224	37.30	34.9
1992	1.91	9.99	0.79	3.94	874	360	1234	41.21	35.4
1993	1.91	11.90	0.91	4.85	875	417	1292	47.63	35.8
1994	1.94	13.85	0.91	5.76	891	417	1308	46.79	36.3
1995	1.96	15.80	0.98	6.75	896	451	1347	50.32	36.8
1996	2.00	17.81	1.11	7.86	918	509	1428	55.49	37.2
1997	2.02	19.83	1.20	9.05	927	549	1476	59.16	37.5
1998	2.04	21.87	1.35	10.40	934	619	1552	66.26	37.8
1999	2.06	23.92	1.50	11.91	942	689	1631	73.08	38.0
2000	2.06	25.98	1.62	13.53	942	742	1684	78.79	38.2
2001	2.00	27.98	1.90	15.43	917	872	1788	95.10	38.3
2002	1.97	29.95	1.96	17.39	901	899	1800	99.70	38.3
2003	1.88	31.83	1.99	19.38	862	911	1773	105.65	38.3
2004	1.91	33.74	2.11	21.49	874	968	1841	110.73	38.2
2005	1.88	35.62	2.38	23.87	862	1090	1952	126.52	38.0
2006	1.86	37.48	2.23	26.09	853	1020	1873	119.64	37.8
2007	1.86	39.34	2.21	28.30	854	1012	1865	118.54	37.6
2008	1.82	41.16	2.11	30.41	832	968	1800	116.24	37.5
2009	1.84	43.00	1.95	32.36	844	893	1737	105.92	37.4
2010	1.77	44.77	1.92	34.29	813	881	1694	108.43	37.3
2011	1.78	46.55	1.85	36.14	814	848	1663	104.14	37.3
2012	1.82	48.36	1.81	37.94	833	829	1662	99.46	37.3
2013	1.83	50.19	1.96	39.90	837	898	1734	107.27	37.1
2014	1.84	52.03	1.61	41.51	843	738	1581	87.57	37.2
2015	1.81	53.84	1.78	43.29	832	814	1646	97.90	37.1
2016	1.82	55.66	1.73	45.02	832	790	1623	95.00	37.1
2017	1.85	57.51	1.47	46.49	846	674	1520	79.68	37.2
2018	1.81	59.32	1.64	48.12	829	749	1578	90.43	37.2
2019	1.79	61.10	1.49	49.61	819	682	1501	83.35	37.2
2020	1.78	62.88	1.41	51.02	817	644	1461	78.87	37.3
2021	1.79	64.67	1.33	52.35	820	608	1428	74.17	37.4
2022	1.72	66.39	1.42	53.77	786	652	1438	82.84	37.5
2023	1.74	68.13	1.27	55.04	797	582	1379	72.95	37.6
2024	1.74	69.87	1.29	56.33	796	591	1387	74.23	37.7
2025	1.71	71.58	1.34	57.67	786	616	1401	78.35	37.8
2026	1.70	73.28	1.32	58.99	780	606	1386	77.74	37.9
2027	1.70	74.98	1.37	60.36	778	628	1406	80.65	37.9
2028	1.72	76.71	1.25	61.61	790	572	1362	72.46	38.0
2029	1.73	78.44	1.44	63.05	794	662	1456	83.33	38.0
2030	1.74	80.18	1.40	64.46	799	642	1441	80.43	37.9
2031	1.76	81.94	1.42	65.88	807	651	1458	80.58	37.9
2032	1.73	83.68	1.53	67.41	794	702	1496	88.44	37.8
2033	1.71	85.39	1.51	68.92	786	692	1477	88.03	37.7
2034	1.69	87.08	1.57	70.49	775	719	1494	92.86	37.6
2035	1.73	88.81	1.69	72.18	791	775	1566	97.95	37.3
2036	1.72	90.52	1.57	73.75	786	721	1506	91.68	37.2
2037	1.70	92.22	1.68	75.44	780	772	1552	98.98	36.9
2038	1.65	93.88	1.68	77.12	758	771	1529	101.71	36.7
2039	1.65	95.53	1.59	78.71	755	730	1485	96.64	36.5
2040	1.67	97.19	1.59	80.31	764	731	1494	95.70	36.4
2041	1.65	98.85	1.67	81.98	757	766	1523	101.11	36.2
2042	1.67	100.52	1.82	83.80	766	835	1600	109.02	35.9
2043	1.71	102.22	1.69	85.49	782	776	1558	99.21	35.6
2044	1.70	103.92	1.72	87.21	779	786	1565	100.94	35.4
2045	1.69	105.61	1.85	89.05	774	846	1620	109.27	35.1
2046	1.68	107.30	1.75	90.80	771	802	1573	103.94	34.8
2047	1.69	108.98	1.96	92.76	772	898	1670	116.20	34.4
2048	1.72	110.70	1.87	94.63	786	856	1642	108.96	34.1
2049	1.72	112.42	1.91	96.55	789	877	1666	111.09	33.8

2050	1.73	114.15	1.72	98.27	791	789	1581	99.76	33.5
2051	1.69	115.84	1.81	100.08	777	832	1608	107.10	33.3
2052	1.74	117.58	1.59	101.68	795	731	1526	91.91	33.2
2053	1.76	119.34	1.78	103.46	806	816	1622	101.26	33.0
2054	1.71	121.05	1.65	105.11	785	755	1540	96.29	32.9
2055	1.75	122.80	1.68	106.79	801	771	1572	96.28	32.7
2056	1.75	124.54	1.58	108.37	800	724	1524	90.40	32.6
2057	1.80	126.34	1.54	109.91	823	706	1529	85.81	32.6
2058	1.75	128.09	1.59	111.50	800	727	1527	90.81	32.6
2059	1.72	129.81	1.38	112.87	790	631	1421	79.90	32.7
2060	1.76	131.57	1.47	114.34	807	674	1481	83.58	32.7
2061	1.78	133.35	1.41	115.75	815	645	1460	79.22	32.8
2062	1.78	135.12	1.40	117.15	814	640	1455	78.61	32.9
2063	1.76	136.88	1.49	118.64	807	683	1490	84.71	32.9
2064	1.81	138.69	1.35	119.99	827	619	1446	74.76	33.1
2065	1.79	140.48	1.39	121.38	821	635	1456	77.36	33.2
2066	1.85	142.33	1.28	122.66	846	589	1435	69.59	33.4
2067	1.82	144.15	1.21	123.87	834	553	1387	66.23	33.6
2068	1.80	145.95	1.33	125.20	825	608	1434	73.70	33.8
2069	1.82	147.77	1.24	126.44	835	570	1406	68.25	34.0
2070	1.85	149.62	1.33	127.77	846	611	1457	72.30	34.2
2071	1.78	151.40	1.19	128.96	817	543	1360	66.52	34.5
2072	1.79	153.19	1.33	130.29	821	607	1428	73.96	34.7
2073	1.77	154.96	1.31	131.60	810	602	1412	74.36	34.8
2074	1.79	156.75	1.31	132.91	820	600	1420	73.22	35.0
2075	1.80	158.55	1.33	134.23	825	607	1432	73.61	35.2
2076	1.82	160.37	1.33	135.56	832	609	1442	73.21	35.4
2077	1.81	162.18	1.34	136.90	831	612	1443	73.71	35.6
2078	1.82	163.99	1.45	138.35	832	663	1495	79.66	35.7
2079	1.80	165.79	1.36	139.71	823	623	1446	75.62	35.8
2080	1.80	167.60	1.54	141.25	827	706	1533	85.39	35.9
2081	1.77	169.37	1.57	142.82	813	721	1534	88.61	35.9
2082	1.84	171.21	1.53	144.35	844	700	1544	82.92	35.9
2083	1.76	172.98	1.40	145.75	809	643	1452	79.56	36.0
2084	1.82	174.80	1.54	147.29	836	705	1541	84.32	36.0
2085	1.82	176.62	1.59	148.88	834	729	1563	87.39	36.0
2086	1.77	178.40	1.61	150.49	813	737	1550	90.64	36.0
2087	1.80	180.20	1.57	152.06	826	718	1545	86.95	36.0
2088	1.80	182.00	1.65	153.71	823	758	1581	92.02	35.9
2089	1.73	183.72	1.66	155.36	792	759	1550	95.84	35.8
2090	1.78	185.50	1.66	157.02	815	759	1574	93.05	35.8
2091	1.73	187.23	1.65	158.67	791	754	1545	95.39	35.7
2092	1.72	188.95	1.65	160.31	787	754	1541	95.88	35.7
2093	1.78	190.72	1.76	162.07	813	806	1619	99.08	35.5
2094	1.77	192.49	1.67	163.74	809	767	1576	94.74	35.4
2095	1.78	194.27	1.57	165.31	815	719	1534	88.28	35.4
2096	1.75	196.02	1.65	166.97	803	757	1560	94.18	35.4
2097	1.77	197.79	1.72	168.69	813	788	1602	96.94	35.2
2098	1.77	199.57	1.65	170.34	812	757	1569	93.13	35.2
2099	1.71	201.28	1.60	171.94	784	735	1518	93.79	35.1
2100	1.76	203.03	1.92	173.86	806	879	1685	109.11	34.9

SUMMARY STATISTICS FOR 1988-2100

ANNUAL AVERAGE REPAIR COST AS % OF CONSTRUCTION COST = 1.80
STANDARD DEVIATION OF ANNUAL REPAIR COST (%) = 0.10
ANNUAL AVERAGE REPLACEMENT COST(%) OUT OF TOTAL BLDG = 1.54
STANDARD DEVIATION OF ANNUAL REPLACEMENT COST (%) = 0.31
ANNUAL AVERAGE REPLACED BUILDINGS IN KILO SQUARE FT. = 705.0
ANNUAL AVERAGE REPAIR COST/ AVERAGE REPLACEMENT COST = 1.17

Output (55 Percent RRC Criterion)

```
tail(right) = ? .01
component                 pessimistic   likely   optimistic   eta    sigma
roofing                       10          25         35        3.7     16
ext. cladding                 30          50         70        2.9     23
ext. door/window              30          60        100        2.5     36
ext. finishes                 15          20         25        2.9      5
int. fin.(long)               75         100        150        2.1     34
int. doors                    40          75        125        2.4     43
int. fin.(short)               7          15         25        2.6      9
mech.-moving                  10          15         25        2.1      6
mech.-static                  30          50         80        2.3     25
electrical                    25          50         75        2.9     28
special                       10          30         50        2.9     23
average_excess_cost_of_repair/construction_cost =  1.23657
repair cost (roofing         ) =   4.0% of net_replacement_cost
repair cost (ext. cladding   ) =  11.1% of net_replacement_cost
repair cost (ext. door/window) =  12.7% of net_replacement_cost
repair cost (ext. finishes   ) =   4.0% of net_replacement_cost
repair cost (int. partitions ) =  18.6% of net_replacement_cost
repair cost (int. doors      ) =   3.7% of net_replacement_cost
repair cost (int. finishes   ) =  12.6% of net_replacement_cost
repair cost (mech.-moving    ) =   5.5% of net_replacement_cost
repair cost (mech.-static    ) =   9.6% of net_replacement_cost
repair cost (electrical      ) =   3.3% of net_replacement_cost
repair cost (special         ) =   5.2% of net_replacement_cost
```

FAMILY HOUSING INVENTORY PROFILE

CONSTRUCTION YEAR FROM - TO	GROSS AREA (K.SQ.FT)	GROSS AREA (% OF TOTAL)
1841 - 1845	10	0.02
1846 - 1850	0	0.00
1851 - 1855	18	0.04
1856 - 1860	8	0.02
1861 - 1865	35	0.08
1866 - 1870	107	0.24
1871 - 1875	20	0.04
1876 - 1880	25	0.06
1881 - 1885	21	0.05
1886 - 1890	98	0.22
1891 - 1895	176	0.40
1896 - 1900	21	0.05
1901 - 1905	651	1.46
1906 - 1910	720	1.62
1911 - 1915	278	0.62
1916 - 1920	97	0.22
1921 - 1925	253	0.57
1926 - 1930	465	1.04
1931 - 1935	2758	6.19
1936 - 1940	1056	2.37
1941 - 1945	275	0.62
1946 - 1950	955	2.14
1951 - 1955	5756	12.93
1956 - 1960	18136	40.73
1961 - 1965	6337	14.23
1966 - 1970	2559	5.75
1971 - 1975	2861	6.43

1976 - 1980	205	0.46
1981 - 1985	550	1.24

INVENTORY BUILT 1841-1985: 44525

DEFINITION ---- NET_REPLACEMENT_COST: Duplication cost excluding cost of site work, design and contract overhead.
RENOVATED VALUE: net replacement cost of a building less depreciation of unreplacable components.

Building is replaced when relative repair cost is more than 55 per cent of the renovated value of a building.

1988-2100 FAMILY HOUSING COST FORECAST FOR REPAIR AND REPLACEMENT IN TRAINING AND DOCTRINE COMMAND

TOTAL AREA (RAW DATA) = 44520 KILO SQUARE FEET
(ADJUSTED DATA) = 45824 KILO SQUARE FEET

YEAR	COST (% OF CONSTR. COST)				COST(KSF. BLDG.EQ.)			CONSTR OVER REPAIR (%)	AVG AGE OF BLDG
	REPAIR		CONSTRUCTION						
	ANNUAL	CUMUL	ANNUAL	CUMUL	REPAIR COST	CONSTR COST	TOTAL COST		
1988	2.12	2.12	0.53	0.53	973	243	1216	24.97	33.6
1989	2.11	4.23	0.52	1.05	967	238	1205	24.59	34.2
1990	2.07	6.30	0.44	1.49	948	203	1151	21.39	34.9
1991	2.02	8.32	0.54	2.03	925	248	1173	26.83	35.6
1992	1.99	10.30	0.48	2.52	910	221	1131	24.32	36.3
1993	2.02	12.33	0.51	3.03	928	235	1162	25.29	36.9
1994	2.04	14.37	0.53	3.56	936	244	1180	26.06	37.6
1995	2.04	16.42	0.59	4.15	937	272	1209	29.00	38.2
1996	2.10	18.52	0.65	4.81	964	300	1263	31.07	38.8
1997	2.20	20.72	0.71	5.52	1009	326	1336	32.33	39.4
1998	2.21	22.93	0.73	6.25	1011	336	1347	33.19	40.0
1999	2.26	25.19	0.96	7.21	1036	442	1478	42.62	40.5
2000	2.27	27.46	1.06	8.28	1039	487	1526	46.85	40.9
2001	2.21	29.67	1.07	9.35	1012	491	1503	48.49	41.3
2002	2.21	31.88	1.21	10.56	1014	556	1570	54.81	41.7
2003	2.24	34.12	1.30	11.86	1028	594	1622	57.76	42.0
2004	2.16	36.29	1.42	13.27	991	649	1641	65.51	42.2
2005	2.18	38.46	1.43	14.71	997	657	1654	65.85	42.5
2006	2.17	40.63	1.44	16.15	994	661	1655	66.45	42.7
2007	2.19	42.82	1.40	17.55	1002	643	1645	64.21	42.9
2008	2.16	44.98	1.43	18.98	990	656	1646	66.21	43.1
2009	2.13	47.12	1.28	20.27	978	588	1566	60.07	43.4
2010	2.13	49.25	1.28	21.55	977	588	1565	60.16	43.6
2011	2.18	51.43	1.34	22.89	1001	613	1614	61.31	43.8
2012	2.20	53.63	1.34	24.23	1008	616	1623	61.08	44.0
2013	2.14	55.77	1.27	25.51	980	584	1564	59.53	44.3
2014	2.18	57.95	1.21	26.72	998	556	1554	55.70	44.5
2015	2.13	60.08	1.23	27.94	978	562	1540	57.47	44.8
2016	2.14	62.22	1.20	29.14	979	550	1529	56.12	45.0
2017	2.12	64.34	1.11	30.26	974	509	1483	52.33	45.3
2018	2.11	66.46	1.10	31.35	968	502	1471	51.87	45.6
2019	2.03	68.49	1.14	32.49	931	521	1452	55.92	45.8

2020	2.06	70.55	1.12	33.61	942	515	1456	54.65	46.1
2021	1.97	72.52	1.06	34.67	904	484	1388	53.49	46.3
2022	1.95	74.47	1.03	35.70	895	471	1366	52.69	46.6
2023	1.91	76.38	1.14	36.83	874	521	1395	59.59	46.8
2024	1.89	78.27	1.15	37.98	867	527	1394	60.79	47.0
2025	1.88	80.15	1.25	39.23	862	571	1433	66.29	47.1
2026	1.86	82.01	1.23	40.46	854	564	1418	66.06	47.1
2027	1.84	83.85	1.33	41.79	843	610	1454	72.37	47.2
2028	1.86	85.72	1.39	43.18	853	636	1489	74.55	47.1
2029	1.83	87.54	1.28	44.47	837	589	1425	70.38	47.2
2030	1.83	89.37	1.44	45.91	838	661	1499	78.85	47.0
2031	1.84	91.21	1.40	47.30	843	640	1484	75.91	47.0
2032	1.82	93.03	1.42	48.73	834	653	1486	78.26	46.9
2033	1.85	94.88	1.52	50.25	846	696	1542	82.21	46.7
2034	1.79	96.67	1.53	51.78	820	702	1522	85.57	46.5
2035	1.77	98.44	1.69	53.47	810	773	1583	95.44	46.2
2036	1.76	100.20	1.66	55.12	808	760	1568	94.01	45.9
2037	1.73	101.93	1.64	56.76	794	749	1543	94.43	45.6
2038	1.69	103.62	1.74	58.50	773	796	1569	102.87	45.2
2039	1.71	105.33	1.63	60.13	783	747	1531	95.40	44.9
2040	1.66	106.99	1.75	61.88	761	804	1565	105.66	44.5
2041	1.67	108.66	1.69	63.57	766	776	1542	101.32	44.1
2042	1.65	110.31	1.84	65.41	756	842	1598	111.39	43.6
2043	1.65	111.96	1.86	67.27	756	852	1609	112.67	43.1
2044	1.65	113.61	1.94	69.21	755	890	1645	118.00	42.5
2045	1.67	115.28	1.96	71.17	766	898	1664	117.15	41.9
2046	1.69	116.97	2.13	73.31	775	978	1752	126.23	41.1
2047	1.67	118.64	1.99	75.30	766	913	1679	119.20	40.5
2048	1.69	120.33	1.99	77.28	776	910	1686	117.20	39.9
2049	1.70	122.04	2.18	79.47	781	999	1780	127.97	39.1
2050	1.68	123.72	1.94	81.40	769	887	1657	115.33	38.4
2051	1.69	125.41	1.85	83.25	774	849	1623	109.74	37.9
2052	1.71	127.11	1.81	85.06	782	828	1609	105.87	37.4
2053	1.71	128.83	1.75	86.81	786	802	1587	102.08	36.9
2054	1.70	130.52	1.76	88.57	778	808	1586	103.91	36.4
2055	1.72	132.24	1.51	90.09	787	693	1480	87.98	36.1
2056	1.72	133.97	1.62	91.71	790	744	1534	94.21	35.8
2057	1.72	135.69	1.51	93.22	789	692	1481	87.64	35.5
2058	1.74	137.43	1.45	94.67	798	666	1464	83.46	35.3
2059	1.80	139.23	1.31	95.98	824	599	1424	72.66	35.2
2060	1.80	141.03	1.26	97.23	824	575	1399	69.83	35.2
2061	1.81	142.83	1.19	98.42	829	543	1372	65.59	35.2
2062	1.84	144.68	1.24	99.66	845	569	1414	67.36	35.2
2063	1.84	146.52	1.05	100.71	843	482	1325	57.15	35.4
2064	1.85	148.37	1.13	101.84	850	517	1367	60.80	35.4
2065	1.89	150.26	0.97	102.82	864	447	1311	51.70	35.7
2066	1.90	152.15	1.06	103.88	868	486	1354	55.94	35.8
2067	1.89	154.04	1.04	104.91	865	475	1340	54.86	36.0
2068	1.90	155.94	0.92	105.83	871	420	1291	48.20	36.3
2069	1.92	157.86	0.95	106.78	880	434	1315	49.35	36.6
2070	1.92	159.79	0.90	107.67	881	411	1291	46.63	36.9
2071	1.92	161.70	0.91	108.58	878	416	1294	47.37	37.2
2072	1.96	163.66	0.85	109.43	898	391	1289	43.54	37.6
2073	1.95	165.61	0.93	110.36	893	426	1319	47.74	37.9
2074	1.97	167.58	0.89	111.26	904	409	1313	45.20	38.2
2075	1.94	169.52	0.81	112.07	887	373	1260	42.00	38.6
2076	1.97	171.49	0.89	112.96	902	410	1312	45.40	39.0
2077	1.96	173.45	0.91	113.87	900	418	1318	46.44	39.3
2078	1.96	175.42	0.97	114.84	900	444	1344	49.29	39.7
2079	1.98	177.39	0.90	115.75	906	414	1320	45.65	40.0

2080	1.97	179.36	1.07	116.82	901	492	1393	54.61	40.3
2081	1.99	181.35	1.06	117.88	912	487	1399	53.38	40.5
2082	2.00	183.35	1.08	118.97	915	497	1413	54.31	40.8
2083	1.98	185.33	1.15	120.12	907	527	1434	58.13	41.0
2084	2.01	187.33	1.13	121.25	919	518	1437	56.34	41.2
2085	2.01	189.34	1.16	122.41	920	533	1453	57.98	41.4
2086	1.98	191.31	1.09	123.50	905	501	1406	55.38	41.6
2087	1.99	193.30	1.24	124.74	910	566	1476	62.20	41.7
2088	2.00	195.30	1.25	125.99	917	573	1490	62.54	41.9
2089	1.98	197.28	1.24	127.23	908	566	1474	62.35	42.0
2090	1.98	199.26	1.27	128.50	908	582	1490	64.02	42.1
2091	1.97	201.23	1.34	129.84	904	616	1519	68.12	42.1
2092	1.96	203.20	1.30	131.14	900	595	1495	66.13	42.2
2093	1.98	205.18	1.36	132.50	908	625	1533	68.78	42.3
2094	1.96	207.14	1.35	133.85	900	617	1516	68.52	42.3
2095	1.97	209.11	1.32	135.17	901	605	1506	67.20	42.4
2096	1.96	211.07	1.42	136.59	899	652	1551	72.44	42.4
2097	1.97	213.04	1.39	137.97	904	635	1539	70.29	42.4
2098	1.96	215.01	1.33	139.31	899	611	1510	68.00	42.5
2099	1.95	216.95	1.27	140.58	892	582	1474	65.17	42.6
2100	1.99	218.94	1.51	142.09	910	693	1603	76.11	42.4

```
              SUMMARY STATISTICS FOR 1988-2100
              -------------------------------
ANNUAL AVERAGE REPAIR COST AS % OF CONSTRUCTION COST = 1.94
        STANDARD DEVIATION OF ANNUAL REPAIR COST (%) = 0.17
ANNUAL AVERAGE REPLACEMENT COST(%) OUT OF TOTAL BLDG = 1.26
   STANDARD DEVIATION OF ANNUAL REPLACEMENT COST (%) = 0.37
ANNUAL AVERAGE REPLACED BUILDINGS IN KILO SQUARE FT. = 576.2
ANNUAL AVERAGE REPAIR COST/ AVERAGE REPLACEMENT COST = 1.54
```

Output (60 Percent RRC Criterion)

```
tail(right) = ? .01
component              pessimistic   likely   optimistic   eta   sigma
roofing                     10         25         35       3.7     16
ext. cladding               30         50         70       2.9     23
ext. door/window            30         60        100       2.5     36
ext. finishes               15         20         25       2.9      5
int. fin.(long)             75        100        150       2.1     34
int. doors                  40         75        125       2.4     43
int. fin.(short)             7         15         25       2.6      9
mech.-moving                10         15         25       2.1      6
mech.-static                30         50         80       2.3     25
electrical                  25         50         75       2.9     28
special                     10         30         50       2.9     23
average_excess_cost_of_repair/construction_cost =  1.23657
repair cost (roofing         ) =  4.0% of net_replacement_cost
repair cost (ext. cladding   ) = 11.1% of net_replacement_cost
repair cost (ext. door/window) = 12.7% of net_replacement_cost
repair cost (ext. finishes   ) =  4.0% of net_replacement_cost
repair cost (int. partitions ) = 18.6% of net_replacement_cost
repair cost (int. doors      ) =  3.7% of net_replacement_cost
repair cost (int. finishes   ) = 12.6% of net_replacement_cost
repair cost (mech.-moving    ) =  5.5% of net_replacement_cost
repair cost (mech.-static    ) =  9.6% of net_replacement_cost
repair cost (electrical      ) =  3.3% of net_replacement_cost
repair cost (special         ) =  5.2% of net_replacement_cost
```

FAMILY HOUSING INVENTORY PROFILE

CONSTRUCTION YEAR FROM - TO	GROSS AREA (K.SQ.FT)	GROSS AREA (% OF TOTAL)
1841 - 1845	10	0.02
1846 - 1850	0	0.00
1851 - 1855	18	0.04
1856 - 1860	8	0.02
1861 - 1865	35	0.08
1866 - 1870	107	0.24
1871 - 1875	20	0.04
1876 - 1880	25	0.06
1881 - 1885	21	0.05
1886 - 1890	98	0.22
1891 - 1895	176	0.40
1896 - 1900	21	0.05
1901 - 1905	651	1.46
1906 - 1910	720	1.62
1911 - 1915	278	0.62
1916 - 1920	97	0.22
1921 - 1925	253	0.57
1926 - 1930	465	1.04
1931 - 1935	2758	6.19
1936 - 1940	1056	2.37
1941 - 1945	275	0.62
1946 - 1950	955	2.14
1951 - 1955	5756	12.93
1956 - 1960	18136	40.73
1961 - 1965	6337	14.23
1966 - 1970	2559	5.75
1971 - 1975	2861	6.43
1976 - 1980	205	0.46
1981 - 1985	550	1.24

INVENTORY BUILT 1841-1985: 44525

DEFINITION ---- NET_REPLACEMENT_COST: Duplication cost excluding cost of site work, design and contract overhead.
RENOVATED VALUE: net replacement cost of a building less depreciation of unreplacable components.

Building is replaced when relative repair cost is more than 60 per cent of the renovated value of a building.

1988-2100 FAMILY HOUSING COST FORECAST FOR REPAIR AND REPLACEMENT IN TRAINING AND DOCTRINE COMMAND

TOTAL AREA (RAW DATA) = 44520 KILO SQUARE FEET
(ADJUSTED DATA) = 45824 KILO SQUARE FEET

YEAR	COST (% OF CONSTR. COST)				COST(KSF. BLDG.EQ.)			CONSTR OVER REPAIR	AVG AGE OF BLDG
	REPAIR		CONSTRUCTION						
	ANNUAL	CUMUL	ANNUAL	CUMUL	REPAIR COST	CONSTR COST	TOTAL COST	(%)	
1988	2.12	2.12	0.31	0.31	971	143	1114	14.74	33.8
1989	2.14	4.25	0.22	0.53	979	102	1081	10.41	34.6
1990	2.07	6.32	0.28	0.81	949	127	1075	13.35	35.4
1991	2.08	8.40	0.32	1.13	951	146	1097	15.37	36.1
1992	2.07	10.47	0.31	1.44	948	140	1088	14.77	36.9
1993	2.05	12.52	0.35	1.78	939	160	1099	16.99	37.7

1994	2.13	14.64	0.33	2.12	974	153	1127	15.75	38.4
1995	2.19	16.83	0.38	2.50	1001	174	1175	17.37	39.2
1996	2.21	19.04	0.37	2.86	1014	168	1182	16.54	39.9
1997	2.31	21.35	0.42	3.28	1057	192	1249	18.22	40.7
1998	2.32	23.67	0.47	3.75	1064	215	1279	20.22	41.4
1999	2.37	26.04	0.50	4.26	1088	231	1318	21.20	42.1
2000	2.40	28.45	0.62	4.88	1102	284	1386	25.78	42.7
2001	2.44	30.89	0.66	5.53	1120	301	1420	26.85	43.3
2002	2.39	33.28	0.73	6.26	1094	332	1426	30.39	43.9
2003	2.41	35.69	0.78	7.04	1105	359	1464	32.51	44.4
2004	2.35	38.04	0.72	7.76	1075	330	1406	30.73	45.0
2005	2.43	40.47	0.72	8.49	1114	331	1446	29.74	45.6
2006	2.40	42.87	0.83	9.31	1100	379	1479	34.44	46.1
2007	2.42	45.29	0.79	10.10	1110	362	1472	32.64	46.7
2008	2.42	47.71	0.93	11.03	1107	426	1533	38.48	47.1
2009	2.43	50.13	0.84	11.87	1111	383	1494	34.45	47.6
2010	2.45	52.58	0.81	12.68	1120	373	1493	33.25	48.1
2011	2.44	55.01	0.81	13.49	1116	371	1487	33.20	48.6
2012	2.45	57.46	0.80	14.29	1123	365	1488	32.54	49.1
2013	2.47	59.94	0.73	15.02	1133	336	1469	29.62	49.6
2014	2.48	62.41	0.74	15.76	1136	340	1475	29.91	50.1
2015	2.42	64.83	0.72	16.48	1108	329	1437	29.73	50.7
2016	2.44	67.27	0.75	17.23	1117	344	1461	30.77	51.1
2017	2.37	69.64	0.72	17.95	1084	329	1413	30.39	51.7
2018	2.38	72.01	0.74	18.69	1090	340	1429	31.17	52.1
2019	2.34	74.35	0.75	19.44	1071	344	1415	32.09	52.6
2020	2.22	76.58	0.73	20.17	1019	333	1353	32.71	53.1
2021	2.20	78.77	0.70	20.87	1008	321	1329	31.86	53.6
2022	2.14	80.92	0.82	21.69	982	375	1356	38.17	54.0
2023	2.09	83.01	0.80	22.48	959	365	1325	38.09	54.4
2024	2.05	85.06	0.86	23.34	941	392	1333	41.67	54.7
2025	2.03	87.09	0.94	24.28	930	429	1359	46.17	55.0
2026	2.04	89.13	0.96	25.23	936	438	1374	46.86	55.2
2027	1.98	91.11	0.97	26.21	906	446	1351	49.21	55.5
2028	2.01	93.12	1.02	27.23	923	469	1392	50.87	55.7
2029	1.99	95.12	1.14	28.37	914	523	1437	57.21	55.8
2030	2.00	97.12	1.20	29.58	916	552	1468	60.23	55.9
2031	2.00	99.12	1.17	30.74	918	535	1453	58.29	55.9
2032	1.96	101.08	1.33	32.08	899	610	1509	67.89	55.9
2033	1.96	103.04	1.21	33.29	898	555	1453	61.75	55.9
2034	1.97	105.01	1.35	34.64	902	621	1522	68.84	55.8
2035	1.89	106.90	1.41	36.05	864	644	1508	74.57	55.7
2036	1.86	108.76	1.40	37.45	852	641	1493	75.29	55.6
2037	1.84	110.59	1.55	39.00	841	711	1553	84.54	55.3
2038	1.80	112.39	1.56	40.56	823	716	1539	87.08	55.0
2039	1.77	114.15	1.61	42.17	809	736	1545	90.91	54.7
2040	1.76	115.91	1.63	43.80	807	748	1555	92.78	54.4
2041	1.73	117.64	1.73	45.53	791	795	1585	100.49	53.9
2042	1.72	119.36	1.83	47.37	789	839	1628	106.30	53.3
2043	1.71	121.07	1.95	49.31	783	893	1677	114.05	52.7
2044	1.71	122.78	1.93	51.25	783	885	1668	113.09	52.0
2045	1.72	124.50	2.13	53.38	788	976	1764	123.80	51.2
2046	1.69	126.19	2.00	55.38	776	918	1694	118.35	50.5
2047	1.71	127.90	2.18	57.56	782	997	1779	127.57	49.5
2048	1.69	129.59	2.06	59.61	776	942	1717	121.44	48.7
2049	1.66	131.26	2.21	61.82	763	1013	1775	132.83	47.8
2050	1.70	132.96	2.16	63.98	781	989	1770	126.66	46.8
2051	1.70	134.66	2.06	66.04	780	942	1722	120.77	46.0
2052	1.70	136.36	1.99	68.03	780	914	1694	117.20	45.2
2053	1.70	138.06	1.85	69.88	779	848	1627	108.86	44.5
2054	1.69	139.76	1.95	71.83	775	891	1667	114.98	43.7
2055	1.74	141.49	1.85	73.68	796	849	1645	106.73	43.0
2056	1.72	143.21	1.85	75.53	788	848	1636	107.60	42.3
2057	1.71	144.92	1.68	77.21	783	770	1553	98.28	41.7
2058	1.71	146.63	1.59	78.80	782	727	1508	92.96	41.2
2059	1.74	148.36	1.41	80.20	795	644	1439	81.04	40.9
2060	1.79	150.15	1.42	81.62	818	651	1469	79.51	40.6

2061	1.78	151.92	1.34	82.96	814	613	1428	75.35	40.3
2062	1.80	153.73	1.28	84.24	827	588	1415	71.08	40.1
2063	1.86	155.59	1.08	85.33	852	497	1350	58.32	40.0
2064	1.84	157.43	1.09	86.42	842	498	1340	59.18	40.0
2065	1.81	159.24	1.00	87.41	831	456	1287	54.87	40.1
2066	1.86	161.10	0.91	88.32	854	419	1273	49.03	40.2
2067	1.90	163.00	0.88	89.21	868	405	1273	46.58	40.3
2068	1.94	164.94	0.91	90.12	890	419	1309	47.05	40.5
2069	1.94	166.88	0.86	90.98	888	395	1283	44.52	40.7
2070	1.96	168.84	0.80	91.78	897	365	1263	40.72	40.9
2071	1.95	170.79	0.71	92.50	895	327	1223	36.56	41.2
2072	1.96	172.75	0.75	93.25	899	344	1243	38.23	41.5
2073	1.98	174.73	0.75	94.00	905	344	1249	37.97	41.8
2074	2.05	176.78	0.72	94.72	938	330	1269	35.22	42.2
2075	2.04	178.82	0.71	95.43	935	327	1262	35.01	42.5
2076	2.02	180.83	0.71	96.14	924	323	1247	34.98	42.9
2077	2.02	182.85	0.64	96.77	926	291	1217	31.46	43.3
2078	2.00	184.86	0.66	97.43	918	304	1222	33.07	43.7
2079	2.01	186.87	0.67	98.11	921	309	1230	33.52	44.2
2080	2.06	188.93	0.64	98.75	945	294	1239	31.15	44.6
2081	2.12	191.05	0.62	99.37	969	283	1252	29.20	45.1
2082	2.09	193.14	0.69	100.06	960	316	1276	32.92	45.5
2083	2.11	195.25	0.75	100.81	968	343	1311	35.40	45.9
2084	2.05	197.30	0.71	101.52	938	327	1266	34.88	46.3
2085	2.12	199.43	0.78	102.30	974	359	1333	36.90	46.6
2086	2.12	201.54	0.70	103.00	970	319	1289	32.90	47.1
2087	2.18	203.72	0.73	103.73	999	335	1334	33.48	47.5
2088	2.19	205.91	0.77	104.50	1005	352	1357	35.04	47.8
2089	2.16	208.07	0.81	105.31	989	373	1362	37.66	48.2
2090	2.13	210.20	0.80	106.12	975	368	1343	37.80	48.6
2091	2.18	212.38	0.79	106.90	999	360	1359	36.06	48.9
2092	2.15	214.53	0.84	107.74	984	385	1369	39.12	49.3
2093	2.15	216.68	0.96	108.70	986	438	1425	44.45	49.5
2094	2.19	218.88	0.90	109.60	1006	412	1418	40.93	49.8
2095	2.19	221.06	0.84	110.44	1003	385	1388	38.38	50.1
2096	2.17	223.23	0.82	111.25	993	374	1367	37.61	50.5
2097	2.20	225.43	0.94	112.19	1007	431	1438	42.82	50.7
2098	2.19	227.62	1.00	113.19	1003	458	1461	45.66	50.9
2099	2.22	229.84	0.87	114.06	1018	398	1417	39.11	51.2
2100	2.15	232.00	1.04	115.10	987	475	1461	48.08	51.4

SUMMARY STATISTICS FOR 1988-2100

ANNUAL AVERAGE REPAIR COST AS % OF CONSTRUCTION COST = 2.05
STANDARD DEVIATION OF ANNUAL REPAIR COST (%) = 0.24
ANNUAL AVERAGE REPLACEMENT COST(%) OUT OF TOTAL BLDG = 1.02
STANDARD DEVIATION OF ANNUAL REPLACEMENT COST (%) = 0.49
ANNUAL AVERAGE REPLACED BUILDINGS IN KILO SQUARE FT. = 466.8
ANNUAL AVERAGE REPAIR COST/ AVERAGE REPLACEMENT COST = 2.02

APPENDIX D:

SIMULATION III—FACILITY MANAGEMENT COST PREDICTION MODEL FOR FORSCOM

Program

```
10  SPN=260
20  FYR=148
30  SP1=SPN+1
40  DIM PYRCOST(SP1),REPFQ(SP1),RPMA(SPN),TRPMA(SPN),RPMAPCT(SPN),XTWICE(SP1)
50  DIM XRTWICE(SP1),COMP$(11),OPT(11),MOST(11),PESS(11),ETA1(11),SIGMA(11)
55  DIM COMPCOST(11),REPCOST(11),REPCOSTP(11),ACTVALUE(SP1),CONAREA(185)
56  DIM BDAGE(SPN),TBDAGE(SPN)
60  REM     SIMULATION MODEL: FORECAST FOR MCA and RPMA COST IN TRADOC
70  REM                       YEARS OF FORECAST --- 1988 TO 2100
80  REM        (1) LIFE OF A BUILDING IS ESTIMATED BY SIMULATING THE LIFE OF EACH
90  REM            BUILDING COMPONENT.
100 REM        (2) THE LIFE LENGTH OF A BUILDING COMPONENT IS ASSUMED FOLLOWING
110 REM            WEIBULL DISTRIBUTION.
120 REM        (3) TO DETERMINE THE PARAMETERS IN WEIBULL DISTRIBUTION OF A
130 REM            COMPONENT, THE LIFE OF A COMPONENT IS ESTIMATED BY THREE WAYS,
140 REM            I.E., OPTIMISTIC, PESSIMISTIC AND MOST LIKELY LIFE LENGTH.
150 REM            (ASSUMPTION IN WEIBULL PARAMETER GENERATION: (a) a component
160 REM            never fails earlier than its pessimistic life length.
170 REM            (b) A probability of a component failure after its optimistic
180 REM            life is less than a given value; this value should be given
190 REM            as an input (TAIL_RIGHT) at the beginning. TAIL_RIGHT = 0.01
200 REM            is recommended.)
201 REM        (4) REPAIR COST OF EACH COMPONENT VARIES UNIFORMLY WITHIN THE
202 REM            RANGE OF PLUS AND TEN PER CENT OF ITS AVERAGE REPAIR COST.
210 REM
220 REM      SUBROUTINE 3000: TO ESTIMATES THE VALUES OF sigma (scale
230 REM            parameter) and eta (shape parameter) in weibull distribution
240 REM
250 REM      SUBROUTINE 4000: TO PROVIDE INPUT DATA OF COMPONENT COST.
255 REM
256 REM      SUBROUTINE 4800: TO GENERATE EXISTING FACILITY PROFILE
260 REM
261 REM      SUBROUTINE 4800: TO GENERATE FACILITY INVENTORY PROFILE.
262 REM
265 REM      SUBROUTINE 5000: TO GENERATE THE OUTPUT.
266 REM
270 REM      ASSUMPTION: MARGINAL CONDITION OF A COMPONENT
280 REM            IF REMAINING LIFE OF A COMPONENT IS LESS THAN 25 PER CENT OF
290 REM            ITS NATURAL LIFE, THE CONDITION OF THE COMPONENT IS ASSUMED
300 REM            MARGINAL.
310 REM
320 REM     DECISION RULE OF BUILDING REPLACEMENT:
330 REM           IF SEVERAL COMPONENTS ARE IN MARGINAL CONDITION AND REPAIR
340 REM           COSTS FOR THESE COMPONENTS EXCEEDS SOME LIMIT IN A CERTAIN
350 REM           YEAR, THEN THE WHOLE BUILDING IS REPLACED.  OTHERWISE, EACH
360 REM           COMPONENT IS USED UNTIL IT FAILS.
370 REM
380 REM     DEFINITION: NET_REPLACEMENT_COST
390 REM           NET REPLACEMENT COST of a building is the cost of duplication
400 REM           EXCLUDING costs of site work, design and contract overhead.
401 REM
402 REM     DEFINITION: RENOVATED VALUE
403 REM           RENOVATED VALUE OF A BUILDING is net replacement cost minus
404 REM           depreciated cost of unreplacable components, e.g., frame
405 REM           foundation.
406 REM
410 GOSUB 3000
420 GOSUB 4000
```

```
425 GOSUB 4500
426 GOSUB 4800
430 RANDOMIZE TIMER
440 PRINT "DEFINITION ---- NET_REPLACEMENT_COST: Duplication cost excluding
450 PRINT "                cost of site work, design and contract overhead."
455 PRINT "                RENOVATED VALUE: net replacement cost of a building"
456 PRINT "                less depreciation of unreplacable components."
470 PRINT
480 INPUT "Building is replaced when relative repair cost is more than ",REP%
490 PRINT "per cent of the renovated value of a building."
500 PRINT
510 SIMUL=5
515 TURN=1000
520 TAREA=0
530 IF REP%<66 THEN EARLY=22 ELSE EARLY=30
535 FOR SML=1 TO SIMUL
540 FOR ITURN=1 TO TURN
550 READ YRBUILT,SF
555 IF YRBUILT=0 THEN 1240
560 BLDGX%=SF/5 : REM --- EACH UNIT OF HOUSING COMPLEX IS CONSIDERED 5K SQ.FT.
570 IF BLDGX%<1 THEN 550
580 FOR BN=1 TO BLDGX%
590 YRZERO=YRBUILT-40  : REM --- A HOUSE BUILT IN 1840 IS INPUTTED AS 40 IN
600 REM                          DATA BUT CONSIDERED YEAR 0 IN THE PROGRAM
640 FOR RY=YRZERO TO SP1 : PYRCOST(RY)=0 : NEXT RY
650 FOR RP=YRZERO TO SPN : RPMA(RP)=0 :NEXT RP
660 FOR RX=YRZERO TO SP1 : XTWICE(RX)=0 : XRTWICE(RX)=0 : NEXT RX
665 FOR RA=YRZERO TO SPN : BDAGE(RA)=RA-YRZERO : NEXT RA
670 FOR C=1 TO 11
680 YRREP=YRZERO
690 REM -------- following function generates a life of component by weibull
700 REM          distribution.
710 PESSC=PESS(C) : SIGMAC=SIGMA(C) : ETA1C=ETA1(C)
720 RPCP=REPCOSTP(C)*(.9+.2*RND)
723 RRD=RND
725 OVFL=10^(-38)
726 IF RRD<OVFL THEN RRD=OVFL
730 FAILTIM=PESSC+SIGMAC*(-LOG(RRD))^(1/ETA1C)
740 YRFAIL=INT(FAILTIM)
750 YRREP=YRREP+YRFAIL                : REM --- year of component failure
760 IF YRREP<FYR THEN 723
770 BYRMAR=YRREP+1-INT(YRFAIL*.25)     : REM --- biginning year of marginal cond.
780 IF BYRMAR>SPN THEN 930
790 IF YRREP>SPN THEN 840
800 REM -------- Repair cost of a component
810 IF C=2 THEN XRTWICE(YRREP)=1 : REM --- To eliminate major double counting
820 IF C=4 AND XRTWICE(YRREP)=1 THEN 870
830 RPMA(YRREP)=RPMA(YRREP)+RPCP
840 IF YRREP>SPN THEN YRREP=SP1
850 REM -------- Following function generates potential repair costs of
860 REM          components which are in marginal condition.
870 FOR MAR=BYRMAR TO YRREP
880 IF C=2 THEN XTWICE(MAR)=1              : REM --- To eliminate major double
890 IF C=4 AND XTWICE(MAR)=1 THEN 910      : REM     counting in costs est.
900 PYRCOST(MAR)=PYRCOST(MAR)+RPCP/ACTVALUE(MAR-YRZERO)
910 NEXT MAR
920 GOTO 723
930 NEXT C
940 REM -------- Following routine simulates a time of replacement.
950 REPYEAR=SP1
960 Y1=EARLY+YRZERO
970 FOR Y=Y1 TO SP1
```

```
980 IF PYRCOST(Y)<REP% THEN 1010
990 PREPY=Y
995 IF PREPY=SP1 THEN 1180
1000 GOTO 1040
1010 NEXT Y
1030 GOTO 1180
1040 PEAKSAVE=PYRCOST(PREPY)
1050 YBG=PREPY+1
1060 REM --- To postpone the replacement as long as possible under the rule.
1070 FOR K=YBG TO SP1
1080 IF PYRCOST(K)>=PEAKSAVE THEN 1110
1090 REPYEAR=K-1
1100 GOTO 1130
1110 PEAKSAVE=PYRCOST(K)
1120 NEXT K
1130 REPFQ(REPYEAR)=REPFQ(REPYEAR)+1     : REM --- annual new construction
1140 REM -------- New repair cycle begins after the replacement
1150 YRZERO=REPYEAR
1160 GOTO 640
1170 REM -------- Annual cost of repair estimation
1180 FOR YR=FYR TO SPN
1190 TRPMA(YR)=TRPMA(YR)+RPMA(YR)
1195 TBDAGE(YR)=TBDAGE(YR)+BDAGE(YR)
1200 NEXT YR
1210 NEXT BN
1220 TAREA=TAREA+5*BLDGX%  : REM --- SUMMING UP TOTAL AREA OF BUILDINGS
1230 NEXT ITURN
1240 RESTORE 6000
1250 NEXT SML
1300 GOSUB 5000 : REM --- TO GENERATE OUTPUT
2990 END
3000 REM -------- "ESTIMATION OF WEIBULL DISTRIBUTION"
3010 REM
3030 INPUT "tail(right) = ";RTAIL
3040 X=LOG(RTAIL)
3050 XX=LOG(-X)
3060 PRINT "component              pessimistic   likely    optimistic   eta   sig
3070 FOR I=1 TO 11 : READ COMP$(I) : NEXT I
3080 FOR I=1 TO 11 : READ OPT(I) : NEXT I
3090 FOR I=1 TO 11 : READ MOST(I) : NEXT I
3100 FOR I=1 TO 11 : READ PESS(I) : NEXT I
3110 FOR CP=1 TO 11
3120 MODE=MOST(CP)-PESS(CP)
3130 TOPT=OPT(CP)-PESS(CP)
3140 RATIO=TOPT/MODE
3150 FOR TA=0 TO 100
3160 ETA=2+.1*TA
3170 TEST=ETA*LOG(RATIO)-LOG(ETA)+LOG(ETA-1)-XX
3180 IF TEST>0 THEN 3200
3190 NEXT TA
3200 RETA=1/ETA
3210 DIV=((ETA-1)/ETA)^RETA
3220 SGMA=MODE/DIV
3230 SIGMA(CP)=INT(SGMA)
3240 ETA1(CP)=ETA
3250 PRINT COMP$(CP);"    ";
3260 PRINT USING"      ###     ";PESS(CP);MOST(CP);OPT(CP);
3270 PRINT USING"    #.#    ";ETA1(CP);
3280 PRINT USING "  ### ";SIGMA(CP)
3290 NEXT CP
```

```
3300 DATA "roofing          ","ext. cladding   ","ext. door/window"
3310 DATA "ext. finishes    ","int. partitions ","int. doors      "
3320 DATA "int. finishes    ","mech.-moving    ","mech.-static    "
3330 DATA "electrical       ","special         "
3340 DATA 35,70,100,25,150,125,25,25,80,75,50
3350 DATA 25,50,60,20,100,75,15,15,50,50,30
3360 DATA 10,30,30,15,75,40,7,10,30,25,10
3370 RETURN
4000 REM "generation of cost data for the replacement of a component"
4010 REM  Most of the repair works requires more cost than construction:
4020 REM     Repair jobs might acompany with some side effects, i.e., plumbing
4030 REM     job frequently damages wall or floor, and require extra labor
4040 REM     to remove the failed components.
4060 FOR I=1 TO 11 : READ COMPCOST(I) : NEXT I
4070 FOR I=1 TO 11 : REPCOST(I)=COMPCOST(I) : NEXT I
4080 REPCOST(1)=1.1*COMPCOST(1)
4090 REPCOST(2)=1.1*COMPCOST(2)+COMPCOST(4)+.05*COMPCOST(10)
4100 REPCOST(3)=1.05*COMPCOST(3)+.05*COMPCOST(4)+.05*COMPCOST(7)
4110 REPCOST(4)=1.5*COMPCOST(4)+.05*COMPCOST(10)
4120 REPCOST(5)=COMPCOST(5)+.15*COMPCOST(10)+.35*COMPCOST(7)
4130 REPCOST(9)=1.3*COMPCOST(9)+.15*COMPCOST(5)+.03*COMPCOST(7)
4140 REPCOST(10)=COMPCOST(10)+.05*COMPCOST(5)+.01*COMPCOST(7)
4150 REPCOST(11)=COMPCOST(11)+.05*COMPCOST(5)+.02*COMPCOST(9)+.02*COMPCOST(10)
4160 REPCOST(11)=REPCOST(11)+.01*COMPCOST(7)
4170 TREPCOST=0
4180 COSTFDN=3.96 : REM --- cost of foundation ($/sq.ft)
4190 COSTFRM=5.45 : REM --- cost of framing ($/sq.ft)
4200 OVERCOST=COSTFDN+COSTFRM
4210 TCONCOST=0
4220 FOR I=1 TO 11
4230 TREPCOST=TREPCOST+REPCOST(I)
4240 NEXT I
4250 FOR I=1 TO 11
4260 TCONCOST=TCONCOST+COMPCOST(I)
4270 NEXT I
4280 REPCON=TREPCOST/TCONCOST
4290 PRINT "average_excess_cost_of_repair/construction_cost = ";REPCON
4300 TCONCOST=TCONCOST+OVERCOST
4310 FOR I=1 TO 11 : REPCOSTP(I)=REPCOST(I)*100/TCONCOST : NEXT I
4320 FOR I=1 TO 11
4330 PRINT "repair cost (";COMP$(I);") = ";
4340 PRINT USING" ##.#";REPCOSTP(I);
4350 PRINT "% of net_replacement_cost"
4360 NEXT I
4370 DATA 1.25,2.66,3.96,0.9,4.82,1.28,4.4,1.9,1.9,.85,1.47
4380 RETURN
4500 REM --- THIS SUBROUTINE GENERATES THE RELATIVE WORTH OF AN OLD FACILITY TO
4510 REM     THE NEW ONE.  LINEAR DEPRECIATION IS ASSUMED.
4520 ANNDEP=OVERCOST/(TCONCOST*75)
4530 FOR Y=1 TO 75
4540 ACTVALUE(Y)=1-Y*ANNDEP
4550 NEXT Y
4555 FOR Y=76 TO SP1 : ACTVALUE(Y)=ACTVALUE(75) : NEXT Y
4560 RETURN
4800 REM --- To generate facility inventory profile
4801 PRINT
4802 PRINT
4803 PRINT "        ________________________________"
4805 PRINT "        FAMILY HOUSING INVENTORY PROFILE"
4810 PRINT "____________________________________________________________"
```

```
4815 PRINT "CONSTRUCTION YEAR            GROSS AREA"
4816 PRINT "   FROM    TO             (K.SQ.FT.)  (% OF TOTAL)"
4820 PRINT "-----------------         ----------   -----------"
4830 FOR Y=1 TO 185 : CONAREA(Y)=0 : NEXT Y
4832 GSF=0
4835 FOR I=1 TO 1000
4840 READ YRBUILT,SF
4843 IF YRBUILT=0 THEN 4860
4845 CONAREA(YRBUILT)=CONAREA(YRBUILT)+SF
4846 GSF=GSF+SF
4850 NEXT I
4860 FOR Y=1 TO 29
4885 BY=41+(Y-1)*5 : BE=BY+4
4890 PAREA=0
4900 FOR Y5=BY TO BE
4905 PAREA=PAREA+CONAREA(Y5)
4910 NEXT Y5
4912 PROAREA=100*PAREA/GSF
4915 YS=1800+BY : YF=1800+BE
4920 PRINT "   ";YS;"-";YF;
4925 PRINT USING "          #####  ";PAREA;
4926 PRINT USING "       ##.##";PROAREA
4930 NEXT Y
4931 PRINT "                     -------"
4932 PRINT "INVENTORY BUILT 1841-1985:";GSF
4935 RESTORE 6000
4940 PRINT
4945 PRINT
4950 RETURN
5000 REM -------- OUTPUT GENERATION
5010 REM
5020 PRINT "_______________________________________________________________"
5030 PRINT
5040 PRINT " 1988-2100 FAMILY HOUSING COST FORECAST FOR REPAIR AND REPLACEMENT"
5045 PRINT "                     IN FORCES COMMAMD"
5050 PRINT "_______________________________________________________________"
5055 NAREA=TAREA/SIMUL
5056 BKAREA=NAREA+214
5057 ADJ=BKAREA/NAREA
5060 PRINT " TOTAL AREA (RAW DATA) =";NAREA;"KILO SQUARE FEET"
5065 PRINT "       (ADJUSTED DATA) =";BKAREA;"KILO SQUARE FEET"
5070 PRINT "_______________________________________________________________"
5080 PRINT
5090 PRINT "YEAR    COST (% OF CONSTR. COST)  COST(KSF. BLDG.EQ.)   CONSTR  AVG"
5100 PRINT "     -------------------------- ------------------     OVER   AGE"
5110 PRINT "        REPAIR      CONSTRUCTION REPAIR CONSTR TOTAL   REPAIR   OF"
5115 PRINT "     ANNUAL CUMUL  ANNUAL CUMUL  COST   COST   COST     (%)    BLDG"
5120 PRINT "---- ------ ------ ------ ------ ------ ------ ------  ------  ----"
5190 TAREA5=TAREA/5
5195 SRPMAPC=0 : SMCAPC=0 : SMCAEQ=0
5196 HOR=SPN-FYR+1
5200 FOR Y=FYR TO SPN
5210 MCAPC=100*REPFQ(Y)/TAREA5
5215 SMCAPC=SMCAPC+MCAPC
5220 RPMAPC=TRPMA(Y)/TAREA5
5225 SRPMAPC=SRPMAPC+RPMAPC
5230 RPMAEQ=ADJ*TRPMA(Y)*5/(100*SIMUL)
5240 MCAEQ=ADJ*REPFQ(Y)*5/SIMUL
5243 AVGAGE=TBDAGE(Y)/TAREA5
5245 SMCAEQ=SMCAEQ+MCAEQ
```

```
5250 TOTEQ=RPMAEQ+MCAEQ
5260 RMRATIO=100*MCAEQ/RPMAEQ
5270 FYEAR=Y+1840
5280 PRINT USING"#### ";FYEAR;
5290 PRINT USING"###.## ";RPMAPC,SRPMAPC,MCAPC,SMCAPC;
5310 PRINT USING" ##### ";RPMAEQ,MCAEQ,TOTEQ;
5320 PRINT USING" ###.##";RMRATIO;
5330 PRINT USING"  ##.#";AVGAGE
5400 NEXT Y
5410 SMCAPC=SMCAPC/HOR
5420 SRPMAPC=SRPMAPC/HOR
5430 SMCAEQ=SMCAEQ/HOR
5440 SRMRATIO=SRPMAPC/SMCAPC
5445 VARRPMA=0 : VARMCA=0
5447 FOR Y=FYR TO SPN
5450 VARRPMA=VARRPMA+(TRPMA(Y)/TAREA5-SRPMAPC)^2
5452 VARMCA=VARMCA+(100*REPFQ(Y)/TAREA5-SMCAPC)^2
5455 NEXT Y
5457 STDRPMA=(VARRPMA/HOR)^.5
5458 STDMCA=(VARMCA/HOR)^.5
5460 PRINT "____________________________________________________________"
5470 PRINT "             SUMMARY STATISTICS FOR 1988-2100"
5480 PRINT "             --------------------------------"
5490 PRINT "ANNUAL AVERAGE REPAIR COST AS % OF CONSTRUCTION COST =";
5500 PRINT USING"##.##";SRPMAPC
5505 PRINT "        STANDARD DEVIATION OF ANNUAL REPAIR COST (%) =";
5506 PRINT USING"##.##";STDRPMA
5510 PRINT "ANNUAL AVERAGE REPLACEMENT COST(%) OUT OF TOTAL BLDG =";
5520 PRINT USING"##.##";SMCAPC
5525 PRINT "   STANDARD DEVIATION OF ANNUAL REPLACEMENT COST (%) =";
5526 PRINT USING"##.##";STDMCA
5530 PRINT "ANNUAL AVERAGE REPLACED BUILDINGS IN KILO SQUARE FT. =";
5540 PRINT USING"####.#";SMCAEQ
5550 PRINT "ANNUAL AVERAGE REPAIR COST/ AVERAGE REPLACEMENT COST =";
5560 PRINT USING"##.##";SRMRATIO
5600 RETURN
5990 REM ------ CONSTRUCTION DATA ENTRY BY CONSTRUCTION YEAR AND KILO SQ. FT.
6000 DATA 40,2,58,12,70,51,75,118,84,18,81,80,85,4,86,43,87,97,88,30,89,188
6010 DATA 90,188,91,88,92,58,93,32,94,21,97,21,102,54,103,200,104,66
6020 DATA 105,96,106,76,107,64,108,48,109,69,109,148,110,215,111,80
6030 DATA 112,73,114,199,116,29,117,134,118,42,119,63,120,262,121,44
6040 DATA 122,6,123,22,125,2,126,2,127,14,128,90,129,32,130,423,131,936
6050 DATA 132,340,133,392,134,952,135,9,136,46,137,3,138,13,139,605
6060 DATA 140,211,141,389,142,954,143,105,144,165,145,5,147,157,148,732
6070 DATA 149,414,150,643,151,1918,152,1598,153,890,154,1947,155,475
6080 DATA 156,773,157,6971,158,8241,159,3072,160,3973,161,2714,162,3570
6090 DATA 163,3004,164,818,165,1806,166,1178,167,235,169,1687,170,581
6100 DATA 171,531,172,698,173,586,174,646,175,2482,176,6369,177,1824
6110 DATA 178,3035,179,1505,180,980,181,1477,182.852,183,1019,184,508,185,12
9990 DATA 0,0
```

Output (50 Percent RRC Criterion)

```
tail(right) = ? .01
component              pessimistic    likely    optimistic    eta    sigma
roofing                     10          25          35        3.7      16
ext. cladding               30          50          70        2.9      23
ext. door/window            30          60         100        2.5      36
ext. finishes               15          20          25        2.9       5
int. fin.(long)             75         100         150        2.1      34
int. doors                  40          75         125        2.4      43
int. fin.(short)             7          15          25        2.6       9
mech.-moving                10          15          25        2.1       6
mech.-static                30          50          80        2.3      25
electrical                  25          50          75        2.9      28
special                     10          30          50        2.9      23
average_excess_cost_of_repair/construction_cost =  1.23657
repair cost (roofing          ) =   4.0% of net_replacement_cost
repair cost (ext. cladding    ) =  11.1% of net_replacement_cost
repair cost (ext. door/window) =  12.7% of net_replacement_cost
repair cost (ext. finishes    ) =   4.0% of net_replacement_cost
repair cost (int. partitions ) =  18.6% of net_replacement_cost
repair cost (int. doors       ) =   3.7% of net_replacement_cost
repair cost (int. finishes    ) =  12.6% of net_replacement_cost
repair cost (mech.-moving     ) =   5.5% of net_replacement_cost
repair cost (mech.-static     ) =   9.6% of net_replacement_cost
repair cost (electrical       ) =   3.3% of net_replacement_cost
repair cost (special          ) =   5.2% of net_replacement_cost
```

FAMILY HOUSING INVENTORY PROFILE

CONSTRUCTION YEAR FROM	TO	GROSS AREA (K.SQ.FT.)	(% OF TOTAL)
1841	1845	0	0.00
1846	1850	0	0.00
1851	1855	0	0.00
1856	1860	12	0.02
1861	1865	0	0.00
1866	1870	51	0.06
1871	1875	118	0.15
1876	1880	0	0.00
1881	1885	102	0.13
1886	1890	546	0.69
1891	1895	199	0.25
1896	1900	21	0.03
1901	1905	416	0.53
1906	1910	620	0.79
1911	1915	352	0.45
1916	1920	530	0.67
1921	1925	74	0.09
1926	1930	561	0.71
1931	1935	2629	3.34
1936	1940	878	1.12
1941	1945	1618	2.06
1946	1950	1946	2.47
1951	1955	6828	8.68
1956	1960	23030	29.28
1961	1965	11912	15.15
1966	1970	3681	4.68
1971	1975	4943	6.28

1976 - 1980	13713	17.44
1981 - 1985	3868	4.92

INVENTORY BUILT 1841-1985: 78650

DEFINITION ---- NET_REPLACEMENT_COST: Duplication cost excluding cost of site work, design and contract overhead.
RENOVATED VALUE: net replacement cost of a building less depreciation of unreplacable components.

Building is replaced when relative repair cost is more than 50 per cent of the renovated value of a building.

1988-2100 FAMILY HOUSING COST FORECAST FOR REPAIR AND REPLACEMENT IN FORCES COMMAMD

TOTAL AREA (RAW DATA) = 78655 KILO SQUARE FEET
(ADJUSTED DATA) = 78869 KILO SQUARE FEET

YEAR	COST (% OF CONSTR. COST)				COST(KSF. BLDG.EQ.)			CONSTR OVER REPAIR	AVG AGE OF BLDG
	REPAIR		CONSTRUCTION		REPAIR	CONSTR	TOTAL		
	ANNUAL	CUMUL	ANNUAL	CUMUL	COST	COST	COST	(%)	
1988	1.79	1.79	0.63	0.63	1411	497	1908	35.25	27.3
1989	1.87	3.65	0.60	1.23	1472	471	1943	32.03	27.9
1990	1.89	5.54	0.52	1.75	1490	409	1899	27.46	28.5
1991	1.95	7.50	0.51	2.25	1540	399	1939	25.92	29.2
1992	1.94	9.44	0.52	2.77	1532	411	1943	26.84	29.9
1993	1.99	11.42	0.59	3.37	1567	466	2033	29.76	30.5
1994	2.03	13.45	0.61	3.97	1601	477	2078	29.82	31.2
1995	2.04	15.49	0.71	4.68	1606	560	2165	34.84	31.8
1996	2.02	17.51	0.78	5.46	1591	617	2208	38.76	32.4
1997	1.98	19.49	0.87	6.34	1561	689	2250	44.14	33.0
1998	1.98	21.47	1.02	7.35	1564	801	2365	51.22	33.5
1999	1.93	23.40	1.07	8.42	1523	840	2363	55.18	33.9
2000	1.93	25.33	1.28	9.69	1518	1007	2525	66.31	34.3
2001	1.93	27.25	1.49	11.19	1521	1177	2698	77.38	34.6
2002	1.94	29.19	1.42	12.60	1530	1116	2646	72.96	34.9
2003	1.94	31.14	1.61	14.21	1534	1269	2803	82.78	35.1
2004	1.92	33.06	1.61	15.82	1517	1268	2785	83.62	35.3
2005	1.90	34.96	1.62	17.44	1500	1276	2777	85.09	35.4
2006	1.87	36.84	1.72	19.16	1477	1359	2835	92.01	35.5
2007	1.89	38.73	1.73	20.89	1490	1368	2858	91.77	35.6
2008	1.81	40.53	1.68	22.58	1426	1328	2753	93.13	35.7
2009	1.84	42.37	1.60	24.18	1449	1265	2715	87.33	35.9
2010	1.84	44.21	1.55	25.73	1449	1223	2672	84.43	36.1
2011	1.84	46.05	1.62	27.35	1451	1277	2728	88.05	36.2
2012	1.87	47.92	1.61	28.96	1478	1267	2745	85.78	36.3
2013	1.88	49.80	1.52	30.48	1485	1196	2681	80.58	36.4
2014	1.91	51.71	1.52	31.99	1507	1197	2705	79.42	36.6
2015	1.89	53.61	1.59	33.59	1494	1256	2750	84.10	36.7
2016	1.92	55.53	1.45	35.04	1517	1144	2661	75.42	36.9
2017	1.91	57.44	1.53	36.56	1506	1204	2711	79.94	37.0
2018	1.92	59.36	1.54	38.10	1514	1211	2725	80.03	37.2
2019	1.91	61.27	1.54	39.64	1504	1215	2719	80.82	37.3

2020	1.86	63.13	1.54	41.18	1470	1214	2684	82.59	37.4
2021	1.86	64.99	1.56	42.74	1469	1228	2697	83.64	37.5
2022	1.81	66.81	1.62	44.35	1430	1274	2705	89.11	37.6
2023	1.80	68.61	1.58	45.93	1418	1245	2664	87.80	37.7
2024	1.78	70.39	1.65	47.59	1407	1303	2710	92.57	37.7
2025	1.77	72.16	1.58	49.17	1396	1246	2642	89.28	37.8
2026	1.76	73.92	1.64	50.81	1390	1294	2683	93.08	37.7
2027	1.76	75.68	1.56	52.36	1390	1228	2618	88.40	37.8
2028	1.74	77.43	1.53	53.89	1376	1207	2583	87.74	37.8
2029	1.73	79.16	1.68	55.58	1367	1329	2696	97.17	37.7
2030	1.73	80.90	1.66	57.23	1368	1307	2674	95.52	37.6
2031	1.74	82.64	1.67	58.91	1376	1319	2694	95.85	37.5
2032	1.74	84.38	1.53	60.44	1372	1210	2583	88.20	37.5
2033	1.75	86.13	1.64	62.08	1377	1296	2673	94.08	37.4
2034	1.77	87.89	1.64	63.72	1394	1292	2686	92.64	37.2
2035	1.73	89.63	1.57	65.29	1367	1234	2602	90.27	37.1
2036	1.75	91.38	1.57	66.86	1382	1241	2623	89.84	37.0
2037	1.72	93.10	1.48	68.34	1354	1169	2523	86.37	37.0
2038	1.74	94.83	1.47	69.81	1369	1156	2525	84.48	36.9
2039	1.69	96.52	1.49	71.30	1333	1176	2509	88.25	36.9
2040	1.71	98.23	1.49	72.79	1351	1176	2527	87.04	36.8
2041	1.69	99.92	1.55	74.34	1333	1221	2555	91.61	36.7
2042	1.67	101.60	1.54	75.88	1320	1217	2538	92.20	36.6
2043	1.69	103.28	1.56	77.44	1329	1229	2559	92.48	36.5
2044	1.67	104.96	1.65	79.09	1319	1299	2618	98.43	36.3
2045	1.69	106.65	1.69	80.78	1334	1332	2665	99.85	36.1
2046	1.69	108.34	1.65	82.43	1335	1303	2638	97.53	35.9
2047	1.69	110.04	1.65	84.08	1337	1305	2641	97.61	35.8
2048	1.70	111.73	1.84	85.92	1338	1449	2787	108.29	35.5
2049	1.71	113.44	1.75	87.67	1346	1381	2726	102.60	35.2
2050	1.72	115.16	1.79	89.46	1360	1413	2773	103.85	35.0
2051	1.70	116.86	1.78	91.24	1338	1406	2744	105.06	34.7
2052	1.73	118.59	1.73	92.98	1364	1367	2730	100.22	34.5
2053	1.71	120.30	1.79	94.77	1346	1413	2759	104.95	34.2
2054	1.68	121.98	1.77	96.54	1327	1396	2723	105.20	34.0
2055	1.73	123.71	1.73	98.27	1367	1365	2731	99.86	33.8
2056	1.72	125.43	1.63	99.90	1355	1287	2642	95.02	33.6
2057	1.69	127.12	1.66	101.56	1336	1307	2642	97.80	33.5
2058	1.72	128.84	1.57	103.12	1355	1235	2591	91.15	33.4
2059	1.69	130.53	1.59	104.72	1336	1257	2593	94.14	33.3
2060	1.76	132.30	1.54	106.26	1392	1216	2608	87.39	33.3
2061	1.75	134.05	1.60	107.86	1382	1263	2646	91.40	33.2
2062	1.73	135.79	1.55	109.41	1368	1220	2588	89.23	33.2
2063	1.74	137.52	1.46	110.87	1369	1154	2523	84.33	33.2
2064	1.76	139.29	1.53	112.40	1391	1203	2595	86.49	33.2
2065	1.75	141.03	1.51	113.91	1378	1188	2567	86.21	33.2
2066	1.75	142.78	1.50	115.41	1376	1184	2561	86.03	33.2
2067	1.76	144.53	1.47	116.87	1385	1158	2543	83.65	33.2
2068	1.77	146.31	1.40	118.27	1398	1103	2501	78.88	33.3
2069	1.78	148.09	1.38	119.65	1407	1085	2492	77.11	33.4
2070	1.80	149.89	1.46	121.11	1423	1151	2574	80.90	33.4
2071	1.79	151.69	1.32	122.43	1413	1040	2453	73.60	33.6
2072	1.77	153.46	1.49	123.91	1398	1173	2572	83.89	33.6
2073	1.79	155.25	1.37	125.29	1412	1081	2493	76.57	33.7
2074	1.80	157.05	1.32	126.61	1419	1045	2464	73.63	33.9
2075	1.78	158.83	1.40	128.01	1404	1107	2511	78.87	34.0
2076	1.81	160.64	1.43	129.44	1428	1124	2552	78.72	34.1
2077	1.80	162.44	1.32	130.76	1418	1042	2460	73.46	34.3
2078	1.79	164.23	1.48	132.24	1412	1166	2578	82.59	34.4
2079	1.80	166.03	1.45	133.69	1424	1141	2565	80.16	34.5

2080	1.79	167.82	1.37	135.05	1408	1078	2486	76.55	34.6
2081	1.78	169.60	1.33	136.38	1407	1051	2458	74.69	34.8
2082	1.82	171.42	1.37	137.75	1437	1079	2516	75.10	34.9
2083	1.80	173.22	1.42	139.18	1416	1123	2539	79.31	35.0
2084	1.78	175.00	1.44	140.62	1407	1138	2546	80.86	35.1
2085	1.78	176.78	1.49	142.11	1404	1178	2583	83.90	35.2
2086	1.80	178.58	1.46	143.57	1419	1150	2569	81.04	35.3
2087	1.80	180.38	1.45	145.02	1420	1146	2566	80.70	35.3
2088	1.81	182.19	1.45	146.48	1424	1146	2570	80.50	35.4
2089	1.80	183.99	1.56	148.03	1420	1227	2647	86.43	35.5
2090	1.79	185.78	1.51	149.54	1410	1187	2597	84.19	35.5
2091	1.80	187.58	1.49	151.03	1422	1172	2594	82.42	35.6
2092	1.81	189.39	1.46	152.48	1430	1148	2578	80.28	35.7
2093	1.76	191.15	1.56	154.04	1389	1230	2619	88.59	35.7
2094	1.78	192.94	1.55	155.59	1406	1219	2625	86.74	35.7
2095	1.80	194.74	1.54	157.12	1419	1212	2631	85.44	35.7
2096	1.79	196.53	1.57	158.70	1412	1240	2652	87.84	35.7
2097	1.78	198.30	1.66	160.36	1402	1313	2714	93.64	35.6
2098	1.76	200.07	1.53	161.89	1392	1207	2599	86.74	35.6
2099	1.78	201.85	1.59	163.48	1403	1252	2655	89.27	35.6
2100	1.76	203.61	1.80	165.28	1388	1421	2809	102.34	35.5

```
              SUMMARY STATISTICS FOR 1988-2100
              -------------------------------
ANNUAL AVERAGE REPAIR COST AS % OF CONSTRUCTION COST = 1.80
        STANDARD DEVIATION OF ANNUAL REPAIR COST (%) = 0.09
ANNUAL AVERAGE REPLACEMENT COST(%) OUT OF TOTAL BLDG = 1.46
   STANDARD DEVIATION OF ANNUAL REPLACEMENT COST (%) = 0.29
ANNUAL AVERAGE REPLACED BUILDINGS IN KILO SQUARE FT. =1153.6
ANNUAL AVERAGE REPAIR COST/ AVERAGE REPLACEMENT COST = 1.23
```

Output (55 Percent RRC Criterion)

```
tail(right) = ? .01
component              pessimistic   likely    optimistic   eta    sigma
roofing                    10          25          35        3.7     16
ext. cladding              30          50          70        2.9     23
ext. door/window           30          60         100        2.5     36
ext. finishes              15          20          25        2.9      5
int. fin.(long)            75         100         150        2.1     34
int. doors                 40          75         125        2.4     43
int. fin.(short)            7          15          25        2.6      9
mech.-moving               10          15          25        2.1      6
mech.-static               30          50          80        2.3     25
electrical                 25          50          75        2.9     28
special                    10          30          50        2.9     23
average_excess_cost_of_repair/construction_cost =  1.23657
repair cost (roofing          ) =   4.0% of net_replacement_cost
repair cost (ext. cladding    ) =  11.1% of net_replacement_cost
repair cost (ext. door/window) =  12.7% of net_replacement_cost
repair cost (ext. finishes    ) =   4.0% of net_replacement_cost
repair cost (int. partitions ) =  18.6% of net_replacement_cost
repair cost (int. doors       ) =   3.7% of net_replacement_cost
repair cost (int. finishes    ) =  12.6% of net_replacement_cost
repair cost (mech.-moving     ) =   5.5% of net_replacement_cost
repair cost (mech.-static     ) =   9.6% of net_replacement_cost
repair cost (electrical       ) =   3.3% of net_replacement_cost
repair cost (special          ) =   5.2% of net_replacement_cost
```

FAMILY HOUSING INVENTORY PROFILE

CONSTRUCTION YEAR FROM - TO	GROSS AREA (K.SQ.FT.)	(% OF TOTAL)
1841 - 1845	0	0.00
1846 - 1850	0	0.00
1851 - 1855	0	0.00
1856 - 1860	12	0.02
1861 - 1865	0	0.00
1866 - 1870	51	0.06
1871 - 1875	118	0.15
1876 - 1880	0	0.00
1881 - 1885	102	0.13
1886 - 1890	546	0.69
1891 - 1895	199	0.25
1896 - 1900	21	0.03
1901 - 1905	416	0.53
1906 - 1910	620	0.79
1911 - 1915	352	0.45
1916 - 1920	530	0.67
1921 - 1925	74	0.09
1926 - 1930	561	0.71
1931 - 1935	2629	3.34
1936 - 1940	878	1.12
1941 - 1945	1618	2.06
1946 - 1950	1946	2.47
1951 - 1955	6828	8.68
1956 - 1960	23030	29.28
1961 - 1965	11912	15.15
1966 - 1970	3681	4.68
1971 - 1975	4943	6.28
1976 - 1980	13713	17.44
1981 - 1985	3868	4.92

INVENTORY BUILT 1841-1985: 78650

DEFINITION ---- NET_REPLACEMENT_COST: Duplication cost excluding cost of site work, design and contract overhead. RENOVATED VALUE: net replacement cost of a building less depreciation of unreplacable components.

Building is replaced when relative repair cost is more than 55 per cent of the renovated value of a building.

1988-2100 FAMILY HOUSING COST FORECAST FOR REPAIR AND REPLACEMENT IN FORCES COMMAMD

TOTAL AREA (RAW DATA) = 78655 KILO SQUARE FEET
(ADJUSTED DATA) = 78869 KILO SQUARE FEET

YEAR	COST (% OF CONSTR. COST) REPAIR ANNUAL	REPAIR CUMUL	CONSTRUCTION ANNUAL	CONSTRUCTION CUMUL	COST(KSF. BLDG.EQ.) REPAIR COST	CONSTR COST	TOTAL COST	CONSTR OVER REPAIR (%)	AVG AGE OF BLDG
1988	1.83	1.83	0.42	0.42	1443	333	1776	23.07	27.4
1989	1.92	3.75	0.37	0.79	1513	291	1804	19.22	28.1
1990	1.94	5.68	0.30	1.09	1526	234	1760	15.31	28.9
1991	1.97	7.65	0.31	1.40	1552	246	1798	15.83	29.7
1992	2.01	9.66	0.35	1.75	1584	279	1863	17.60	30.5

1993	2.01	11.67	0.33	2.08	1585	262	1847	16.51	31.3
1994	2.09	13.76	0.39	2.48	1649	309	1957	18.73	32.0
1995	2.11	15.87	0.42	2.90	1661	333	1994	20.04	32.8
1996	2.11	17.98	0.48	3.38	1665	381	2046	22.88	33.5
1997	2.12	20.10	0.53	3.91	1674	420	2094	25.10	34.2
1998	2.09	22.19	0.64	4.55	1645	503	2148	30.61	34.9
1999	2.06	24.25	0.69	5.24	1625	540	2166	33.25	35.5
2000	2.08	26.32	0.73	5.96	1638	573	2211	34.95	36.1
2001	2.11	28.43	0.83	6.79	1662	651	2312	39.16	36.7
2002	2.12	30.55	0.85	7.64	1675	673	2348	40.17	37.2
2003	2.16	32.72	0.92	8.56	1707	728	2435	42.66	37.8
2004	2.15	34.87	1.01	9.58	1697	800	2498	47.14	38.2
2005	2.12	36.99	1.09	10.67	1675	861	2536	51.42	38.7
2006	2.13	39.13	1.13	11.80	1683	889	2573	52.83	39.1
2007	2.16	41.28	1.04	12.84	1700	819	2520	48.18	39.5
2008	2.12	43.40	1.12	13.96	1669	882	2552	52.86	39.9
2009	2.12	45.52	1.08	15.03	1674	848	2522	50.68	40.3
2010	2.09	47.61	1.02	16.05	1649	802	2451	48.66	40.7
2011	2.12	49.73	1.03	17.08	1671	812	2483	48.60	41.1
2012	2.12	51.85	1.04	18.12	1674	823	2497	49.17	41.5
2013	2.17	54.03	1.00	19.12	1713	790	2503	46.12	41.9
2014	2.15	56.18	0.96	20.09	1699	758	2457	44.63	42.4
2015	2.22	58.40	1.03	21.11	1752	812	2564	46.36	42.8
2016	2.22	60.62	1.00	22.11	1750	788	2538	45.04	43.2
2017	2.20	62.82	1.01	23.12	1733	796	2529	45.94	43.6
2018	2.19	65.01	1.01	24.13	1727	795	2522	46.06	43.9
2019	2.15	67.16	1.10	25.23	1696	866	2562	51.09	44.3
2020	2.13	69.29	1.07	26.30	1683	842	2526	50.03	44.6
2021	2.13	71.42	1.09	27.39	1680	863	2544	51.38	45.0
2022	2.08	73.50	1.23	28.62	1639	967	2606	58.97	45.2
2023	2.07	75.57	1.13	29.75	1630	890	2520	54.64	45.5
2024	2.01	77.57	1.20	30.95	1583	946	2528	59.75	45.8
2025	1.99	79.56	1.19	32.14	1568	939	2506	59.87	46.0
2026	1.95	81.51	1.28	33.42	1536	1013	2549	65.92	46.2
2027	1.96	83.46	1.27	34.69	1542	998	2540	64.70	46.3
2028	1.94	85.41	1.31	36.00	1533	1035	2568	67.49	46.4
2029	1.94	87.35	1.36	37.35	1533	1070	2603	69.81	46.5
2030	1.95	89.31	1.38	38.73	1542	1087	2629	70.50	46.6
2031	1.95	91.26	1.38	40.11	1541	1086	2626	70.49	46.6
2032	1.95	93.21	1.43	41.54	1539	1129	2668	73.38	46.6
2033	1.93	95.14	1.46	43.00	1525	1151	2676	75.49	46.5
2034	1.93	97.07	1.47	44.47	1520	1158	2679	76.17	46.5
2035	1.91	98.98	1.46	45.93	1506	1154	2660	76.64	46.4
2036	1.88	100.86	1.44	47.37	1485	1132	2618	76.21	46.3
2037	1.84	102.71	1.54	48.91	1453	1213	2667	83.49	46.1
2038	1.83	104.54	1.47	50.37	1441	1157	2599	80.28	46.0
2039	1.77	106.30	1.55	51.93	1395	1224	2620	87.74	45.8
2040	1.76	108.07	1.48	53.40	1390	1164	2554	83.75	45.6
2041	1.78	109.85	1.46	54.86	1405	1152	2557	81.99	45.5
2042	1.73	111.58	1.55	56.41	1368	1223	2592	89.41	45.2
2043	1.71	113.29	1.65	58.07	1347	1304	2650	96.79	44.9
2044	1.73	115.02	1.72	59.79	1363	1356	2719	99.44	44.6
2045	1.70	116.72	1.67	61.46	1345	1320	2664	98.14	44.2
2046	1.72	118.44	1.79	63.25	1354	1413	2767	104.32	43.8
2047	1.72	120.16	1.84	65.09	1356	1449	2805	106.85	43.3
2048	1.72	121.88	1.83	66.91	1354	1440	2794	106.32	42.8
2049	1.71	123.58	1.97	68.89	1345	1557	2903	115.74	42.2
2050	1.70	125.29	1.89	70.77	1343	1487	2830	110.70	41.6
2051	1.72	127.01	1.82	72.59	1360	1435	2795	105.52	41.1
2052	1.71	128.72	1.93	74.52	1350	1524	2874	112.90	40.5
2053	1.69	130.41	1.79	76.31	1333	1410	2743	105.73	40.1
2054	1.71	132.13	1.82	78.13	1352	1437	2789	106.28	39.6
2055	1.70	133.82	1.74	79.87	1338	1373	2711	102.58	39.1
2056	1.72	135.55	1.74	81.61	1360	1370	2730	100.71	38.7
2057	1.72	137.27	1.63	83.25	1355	1289	2644	95.18	38.3

2058	1.68	138.95	1.60	84.85	1328	1265	2593	95.32	38.0
2059	1.72	140.67	1.49	86.34	1358	1174	2533	86.44	37.8
2060	1.76	142.43	1.44	87.78	1385	1139	2524	82.26	37.6
2061	1.76	144.19	1.43	89.21	1391	1125	2517	80.85	37.4
2062	1.74	145.93	1.39	90.60	1374	1098	2472	79.94	37.2
2063	1.77	147.70	1.39	91.99	1392	1093	2485	78.49	37.1
2064	1.78	149.48	1.41	93.40	1401	1110	2511	79.24	36.9
2065	1.79	151.26	1.36	94.76	1410	1076	2486	76.31	36.8
2066	1.80	153.06	1.30	96.06	1418	1029	2446	72.57	36.8
2067	1.80	154.86	1.28	97.34	1419	1010	2429	71.14	36.7
2068	1.83	156.69	1.37	98.71	1444	1080	2524	74.76	36.6
2069	1.87	158.56	1.33	100.04	1474	1047	2521	71.03	36.5
2070	1.82	160.38	1.28	101.32	1433	1006	2438	70.20	36.5
2071	1.86	162.24	1.24	102.56	1469	980	2448	66.70	36.5
2072	1.85	164.09	1.22	103.77	1463	959	2421	65.53	36.6
2073	1.88	165.97	1.12	104.90	1480	886	2366	59.91	36.7
2074	1.86	167.83	1.13	106.03	1468	891	2359	60.74	36.8
2075	1.90	169.73	1.10	107.13	1498	869	2368	58.03	36.9
2076	1.88	171.61	1.06	108.19	1483	839	2322	56.60	37.1
2077	1.88	173.49	1.09	109.28	1485	860	2345	57.94	37.3
2078	1.90	175.40	1.03	110.31	1502	811	2313	54.00	37.5
2079	1.91	177.30	1.04	111.36	1503	823	2326	54.77	37.7
2080	1.94	179.24	1.03	112.39	1529	813	2342	53.19	37.9
2081	1.93	181.18	1.03	113.42	1526	813	2339	53.29	38.2
2082	1.92	183.10	0.98	114.39	1518	769	2287	50.68	38.5
2083	1.93	185.03	1.00	115.40	1521	789	2310	51.90	38.7
2084	1.97	187.00	1.08	116.48	1554	853	2407	54.92	39.0
2085	1.94	188.94	1.05	117.53	1532	828	2361	54.05	39.2
2086	1.97	190.91	1.03	118.56	1551	811	2362	52.30	39.5
2087	1.97	192.88	1.14	119.69	1554	896	2451	57.68	39.7
2088	1.96	194.84	1.08	120.77	1547	848	2395	54.83	39.9
2089	1.98	196.82	1.11	121.88	1559	879	2438	56.41	40.1
2090	1.99	198.81	1.11	122.99	1573	874	2448	55.58	40.3
2091	1.97	200.78	1.15	124.15	1554	910	2465	58.58	40.5
2092	1.98	202.76	1.20	125.35	1562	949	2511	60.73	40.7
2093	1.98	204.74	1.14	126.49	1562	902	2465	57.76	40.9
2094	1.95	206.70	1.18	127.67	1541	928	2468	60.19	41.1
2095	1.98	208.68	1.18	128.85	1561	930	2490	59.55	41.2
2096	1.96	210.64	1.21	130.06	1547	955	2502	61.69	41.4
2097	1.95	212.59	1.28	131.34	1540	1009	2549	65.50	41.5
2098	1.97	214.57	1.28	132.62	1557	1011	2568	64.92	41.6
2099	1.95	216.52	1.31	133.93	1538	1034	2572	67.20	41.7
2100	1.96	218.48	1.35	135.28	1546	1064	2610	68.81	41.7

SUMMARY STATISTICS FOR 1988-2100

ANNUAL AVERAGE REPAIR COST AS % OF CONSTRUCTION COST = 1.93
STANDARD DEVIATION OF ANNUAL REPAIR COST (%) = 0.15
ANNUAL AVERAGE REPLACEMENT COST(%) OUT OF TOTAL BLDG = 1.20
STANDARD DEVIATION OF ANNUAL REPLACEMENT COST (%) = 0.37
ANNUAL AVERAGE REPLACED BUILDINGS IN KILO SQUARE FT. = 944.2
ANNUAL AVERAGE REPAIR COST/ AVERAGE REPLACEMENT COST = 1.62

Output (60 Percent RRC Criterion)

```
tail(right) = ? .01
component            pessimistic   likely   optimistic   eta   sigma
roofing                   10          25        35        3.7    16
ext. cladding             30          50        70        2.9    23
ext. door/window          30          60       100        2.5    36
ext. finishes             15          20        25        2.9     5
int. fin.(long)           75         100       150        2.1    34
int. doors                40          75       125        2.4    43
int. fin.(short)           7          15        25        2.6     9
mech.-moving              10          15        25        2.1     6
mech.-static              30          50        80        2.3    25
electrical                25          50        75        2.9    28
special                   10          30        50        2.9    23
average_excess_cost_of_repair/construction_cost =  1.23657
repair cost (roofing          ) =  4.0% of net_replacement_cost
repair cost (ext. cladding    ) = 11.1% of net_replacement_cost
repair cost (ext. door/window) = 12.7% of net_replacement_cost
repair cost (int. partitions ) =  4.0% of net_replacement_cost
repair cost (int. doors       ) = 18.6% of net_replacement_cost
repair cost (int. finishes    ) =  3.7% of net_replacement_cost
repair cost (int. fin.(short)) = 12.6% of net_replacement_cost
repair cost (mech.-moving     ) =  5.5% of net_replacement_cost
repair cost (mech.-static     ) =  9.6% of net_replacement_cost
repair cost (electrical       ) =  3.3% of net_replacement_cost
repair cost (special          ) =  5.2% of net_replacement_cost
```

FAMILY HOUSING INVENTORY PROFILE

CONSTRUCTION YEAR FROM	TO	GROSS AREA (K.SQ.FT.)	(% OF TOTAL)
1841	1845	0	0.00
1846	1850	0	0.00
1851	1855	0	0.00
1856	1860	12	0.02
1861	1865	0	0.00
1866	1870	51	0.06
1871	1875	118	0.15
1876	1880	0	0.00
1881	1885	102	0.13
1886	1890	546	0.69
1891	1895	199	0.25
1896	1900	21	0.03
1901	1905	416	0.53
1906	1910	620	0.79
1911	1915	352	0.45
1916	1920	530	0.67
1921	1925	74	0.09
1926	1930	561	0.71
1931	1935	2629	3.34
1936	1940	878	1.12
1941	1945	1618	2.06
1946	1950	1946	2.47
1951	1955	6828	8.68
1956	1960	23030	29.28
1961	1965	11912	15.15
1966	1970	3681	4.68
1971	1975	4943	6.28

1976 - 1980	13713	17.44
1981 - 1985	3868	4.92

INVENTORY BUILT 1841-1985:	78650	

DEFINITION ---- NET_REPLACEMENT_COST: Duplication cost excluding cost of site work, design and contract overhead.
RENOVATED VALUE: net replacement cost of a building less depreciation of unreplacable components.

Building is replaced when relative repair cost is more than 60 per cent of the renovated value of a building.

1988-2100 FAMILY HOUSING COST FORECAST FOR REPAIR AND REPLACEMENT IN FORCES COMMAMD

TOTAL AREA (RAW DATA) = 78655 KILO SQUARE FEET
(ADJUSTED DATA) = 78869 KILO SQUARE FEET

YEAR	COST (% OF CONSTR. COST)				COST(KSF. BLDG.EQ.)			CONSTR OVER REPAIR (%)	AVG AGE OF BLDG
	REPAIR		CONSTRUCTION						
	ANNUAL	CUMUL	ANNUAL	CUMUL	REPAIR COST	CONSTR COST	TOTAL COST		
1988	1.87	1.87	0.25	0.25	1478	194	1672	13.09	27.5
1989	1.97	3.84	0.22	0.47	1551	174	1725	11.25	28.4
1990	1.94	5.78	0.20	0.67	1529	159	1689	10.42	29.2
1991	1.99	7.77	0.19	0.86	1572	147	1720	9.38	30.1
1992	2.04	9.82	0.21	1.07	1612	167	1780	10.39	30.9
1993	2.07	11.88	0.20	1.27	1630	160	1790	9.84	31.8
1994	2.12	14.01	0.22	1.49	1675	171	1846	10.24	32.6
1995	2.16	16.17	0.22	1.70	1702	170	1873	10.01	33.5
1996	2.18	18.35	0.22	1.92	1722	173	1895	10.08	34.3
1997	2.19	20.54	0.35	2.27	1727	273	2000	15.79	35.1
1998	2.20	22.74	0.35	2.62	1733	273	2006	15.74	35.9
1999	2.21	24.95	0.37	2.98	1746	290	2036	16.60	36.7
2000	2.21	27.16	0.42	3.40	1739	330	2069	18.97	37.5
2001	2.22	29.38	0.43	3.83	1751	337	2088	19.24	38.2
2002	2.26	31.63	0.51	4.34	1779	401	2180	22.55	39.0
2003	2.30	33.93	0.53	4.86	1811	415	2226	22.92	39.7
2004	2.31	36.24	0.55	5.41	1820	431	2251	23.69	40.4
2005	2.32	38.56	0.55	5.96	1830	434	2265	23.72	41.1
2006	2.33	40.88	0.64	6.60	1836	503	2339	27.42	41.7
2007	2.34	43.22	0.66	7.26	1846	518	2364	28.08	42.3
2008	2.32	45.55	0.62	7.87	1832	486	2319	26.54	43.0
2009	2.30	47.85	0.68	8.55	1818	536	2354	29.51	43.6
2010	2.30	50.15	0.64	9.19	1816	503	2319	27.72	44.2
2011	2.34	52.50	0.65	9.84	1847	510	2357	27.64	44.8
2012	2.36	54.85	0.60	10.44	1858	476	2334	25.64	45.4
2013	2.35	57.20	0.65	11.10	1854	515	2369	27.80	46.0
2014	2.41	59.61	0.60	11.70	1898	474	2372	24.99	46.7
2015	2.44	62.05	0.61	12.30	1925	477	2403	24.79	47.3
2016	2.43	64.48	0.60	12.90	1917	472	2389	24.64	47.9
2017	2.44	66.92	0.65	13.55	1928	514	2442	26.69	48.5
2018	2.42	69.34	0.66	14.21	1909	520	2429	27.26	49.1
2019	2.36	71.70	0.69	14.91	1860	547	2408	29.43	49.6

2020	2.37	74.07	0.65	15.56	1866	516	2383	27.67	50.2
2021	2.31	76.38	0.71	16.27	1825	560	2385	30.66	50.7
2022	2.30	78.69	0.75	17.03	1818	595	2412	32.72	51.2
2023	2.24	80.92	0.80	17.83	1764	633	2397	35.87	51.7
2024	2.22	83.15	0.85	18.67	1753	667	2420	38.03	52.1
2025	2.20	85.35	0.85	19.52	1736	667	2403	38.41	52.5
2026	2.17	87.52	0.89	20.41	1708	703	2411	41.14	52.9
2027	2.17	89.68	0.92	21.33	1709	723	2432	42.31	53.3
2028	2.12	91.80	1.00	22.33	1670	787	2457	47.13	53.6
2029	2.14	93.94	1.04	23.36	1685	817	2502	48.51	53.8
2030	2.14	96.08	0.99	24.36	1688	784	2472	46.45	54.1
2031	2.15	98.23	1.13	25.48	1696	887	2583	52.34	54.3
2032	2.15	100.37	1.07	26.55	1695	843	2538	49.76	54.5
2033	2.12	102.49	1.18	27.73	1670	932	2602	55.76	54.6
2034	2.12	104.61	1.24	28.98	1670	982	2652	58.77	54.6
2035	2.05	106.66	1.18	30.15	1616	928	2544	57.40	54.7
2036	2.05	108.71	1.22	31.37	1621	964	2584	59.46	54.7
2037	2.02	110.73	1.32	32.69	1591	1038	2629	65.22	54.7
2038	1.96	112.69	1.26	33.95	1543	991	2534	64.21	54.7
2039	1.92	114.61	1.37	35.32	1514	1081	2595	71.39	54.6
2040	1.86	116.46	1.32	36.64	1464	1041	2505	71.09	54.5
2041	1.83	118.29	1.39	38.02	1444	1094	2538	75.77	54.4
2042	1.81	120.11	1.57	39.59	1430	1234	2664	86.33	54.1
2043	1.77	121.88	1.67	41.26	1396	1317	2712	94.33	53.7
2044	1.77	123.65	1.63	42.89	1397	1289	2687	92.29	53.3
2045	1.79	125.44	1.59	44.49	1411	1256	2668	89.01	53.0
2046	1.80	127.23	1.70	46.19	1417	1341	2758	94.61	52.5
2047	1.75	128.99	1.83	48.02	1382	1444	2825	104.51	52.0
2048	1.78	130.76	1.80	49.82	1402	1422	2824	101.42	51.4
2049	1.75	132.51	1.93	51.74	1380	1519	2899	110.06	50.8
2050	1.80	134.31	1.88	53.62	1418	1482	2900	104.52	50.1
2051	1.77	136.08	1.95	55.57	1392	1536	2929	110.32	49.4
2052	1.79	137.87	1.99	57.56	1415	1570	2985	110.96	48.7
2053	1.76	139.64	1.83	59.39	1391	1442	2833	103.66	48.1
2054	1.73	141.37	1.86	61.25	1368	1469	2837	107.36	47.4
2055	1.74	143.11	1.81	63.07	1376	1431	2807	103.99	46.8
2056	1.73	144.84	1.73	64.80	1361	1363	2724	100.11	46.2
2057	1.73	146.57	1.71	66.51	1363	1350	2713	99.02	45.7
2058	1.72	148.29	1.59	68.10	1357	1257	2615	92.65	45.3
2059	1.74	150.03	1.57	69.68	1374	1241	2616	90.32	44.8
2060	1.72	151.76	1.48	71.15	1359	1164	2523	85.68	44.5
2061	1.73	153.48	1.47	72.62	1363	1156	2519	84.82	44.2
2062	1.74	155.23	1.48	74.10	1376	1166	2542	84.76	43.8
2063	1.77	157.00	1.49	75.58	1394	1174	2569	84.20	43.5
2064	1.80	158.79	1.41	76.99	1417	1110	2527	78.33	43.2
2065	1.79	160.59	1.38	78.37	1414	1086	2500	76.79	42.9
2066	1.79	162.37	1.35	79.72	1408	1064	2472	75.55	42.7
2067	1.83	164.20	1.31	81.03	1442	1032	2474	71.55	42.5
2068	1.86	166.06	1.36	82.38	1465	1069	2534	72.98	42.2
2069	1.83	167.88	1.28	83.67	1440	1013	2453	70.32	42.0
2070	1.86	169.75	1.27	84.93	1469	1001	2470	68.11	41.9
2071	1.87	171.61	1.27	86.20	1472	999	2471	67.83	41.7
2072	1.87	173.49	1.15	87.35	1477	905	2383	61.29	41.6
2073	1.86	175.35	1.14	88.49	1471	901	2372	61.30	41.6
2074	1.90	177.25	1.05	89.54	1502	829	2331	55.22	41.6
2075	1.91	179.16	1.02	90.56	1504	803	2307	53.40	41.6
2076	1.92	181.08	0.96	91.52	1517	754	2271	49.70	41.7
2077	1.94	183.02	0.92	92.44	1530	728	2258	47.58	41.9
2078	1.92	184.95	0.86	93.30	1517	677	2194	44.62	42.1
2079	1.97	186.92	0.91	94.20	1556	714	2270	45.89	42.2

2080	1.95	188.87	0.81	95.02	1539	642	2181	41.69	42.5
2081	1.97	190.84	0.82	95.84	1551	648	2198	41.77	42.8
2082	2.00	192.84	0.83	96.67	1580	656	2236	41.50	43.0
2083	2.05	194.89	0.71	97.38	1618	561	2179	34.64	43.4
2084	2.05	196.95	0.78	98.16	1620	618	2238	38.12	43.7
2085	2.06	199.01	0.73	98.89	1627	576	2202	35.38	44.1
2086	2.06	201.07	0.70	99.60	1625	556	2181	34.18	44.5
2087	2.07	203.15	0.78	100.38	1636	613	2249	37.44	44.9
2088	2.09	205.23	0.77	101.15	1646	610	2256	37.03	45.2
2089	2.11	207.35	0.72	101.87	1666	568	2233	34.08	45.6
2090	2.11	209.45	0.75	102.62	1663	591	2253	35.52	46.0
2091	2.12	211.58	0.78	103.39	1676	612	2287	36.50	46.4
2092	2.14	213.72	0.72	104.12	1691	572	2262	33.81	46.8
2093	2.13	215.85	0.76	104.88	1676	603	2279	35.96	47.1
2094	2.13	217.98	0.76	105.64	1679	602	2281	35.83	47.5
2095	2.13	220.11	0.77	106.41	1681	608	2288	36.16	47.9
2096	2.13	222.23	0.81	107.22	1676	637	2313	37.98	48.3
2097	2.14	224.37	0.83	108.05	1687	652	2339	38.64	48.6
2098	2.17	226.54	0.83	108.87	1709	651	2360	38.07	49.0
2099	2.15	228.69	0.82	109.69	1696	646	2342	38.08	49.3
2100	2.15	230.84	0.90	110.59	1695	712	2407	42.00	49.6

SUMMARY STATISTICS FOR 1988-2100

ANNUAL AVERAGE REPAIR COST AS % OF CONSTRUCTION COST = 2.04
STANDARD DEVIATION OF ANNUAL REPAIR COST (%) = 0.21
ANNUAL AVERAGE REPLACEMENT COST(%) OUT OF TOTAL BLDG = 0.98
STANDARD DEVIATION OF ANNUAL REPLACEMENT COST (%) = 0.47
ANNUAL AVERAGE REPLACED BUILDINGS IN KILO SQUARE FT. = 771.9
ANNUAL AVERAGE REPAIR COST/ AVERAGE REPLACEMENT COST = 2.09

USA-CERL DISTRIBUTION

Chief of Engineers
ATTN: Tech Monitor
ATTN: CEIM-SL (2)
ATTN: CECW
ATTN: CECC-P
ATTN: CEEC
ATTN: CEEC-C
ATTN: CEEC-E
ATTN: CERD
ATTN: CERD-C
ATTN: CERD-M
ATTN: CERM
ATTN: DAEN-ZCI
ATTN: DAEN-ZCP

EHSC, ATTN: Library 22060
ATTN: DET III 79906

US Army Europe
AEAEN-ODCS/Engr (2) 09403
AEUES 09081
V Corps
ATTN: DEH (12)
VII Corps
ATTN: DEH (16)
21st Support Command
ATTN: DEH (12)

US Military Academy 10966
ATTN: Facilities Engineer
ATTN: MAEN-A

AMC - Dir., Inst., & Servc
ATTN: DEH (23)

FORSCOM
FORSCOM Engr, ATTN: Spt. Det.
ATTN: DEH (28)

HSC
Ft. Sam Houston AMC 78234
ATTN: HSLO-F
Fitzsimons AMC 80045
ATTN: HSHG-DEH
Walter Reed AMC 20307
ATTN: Facilities Engineer

INSCOM - Ch, Instl. Div
ATTN: Facilities Engineer (5)

MDW, ATTN: DEH (3)

MTMC
ATTN: MT-LOF 20315
ATTN: Facilities Engineer (3)

TRADOC
HQ, TRADOC, ATTN: ATEN-DEH
ATTN: DEH (18)

WESTCOM
ATTN: DEH, Ft. Shafter 96858
ATTN: APEN-A

FORT BELVOIR, VA 22060
ATTN: Canadian Liaison Officer
ATTN: British Liaison Officer
ATTN: Australian Liaison Officer
ATTN: French Liaison Officer
ATTN: German Liaison Officer
ATTN: Water Resources Support Ctr
ATTN: Engr Studies Center
ATTN: Engr Topographic Lab.
ATTN: ATZA-TE-SU
ATTN: STRBE-BLURE

CECRL, ATTN: Library 03755

WES, ATTN: Library 39180

NAVFAC
ATTN: Naval Public Works Center (9)
ATTN: Naval Civil Engr Lab. (2)

NCEL
ATTN: Library, Code L08A 93043

Defense Technical Info. Center 22314
ATTN: DDA (2)

Engr Societies Library, NY 10017

US Govt Print Office 22304
Receiving Sect/Depository Copies (2)

178
10/88